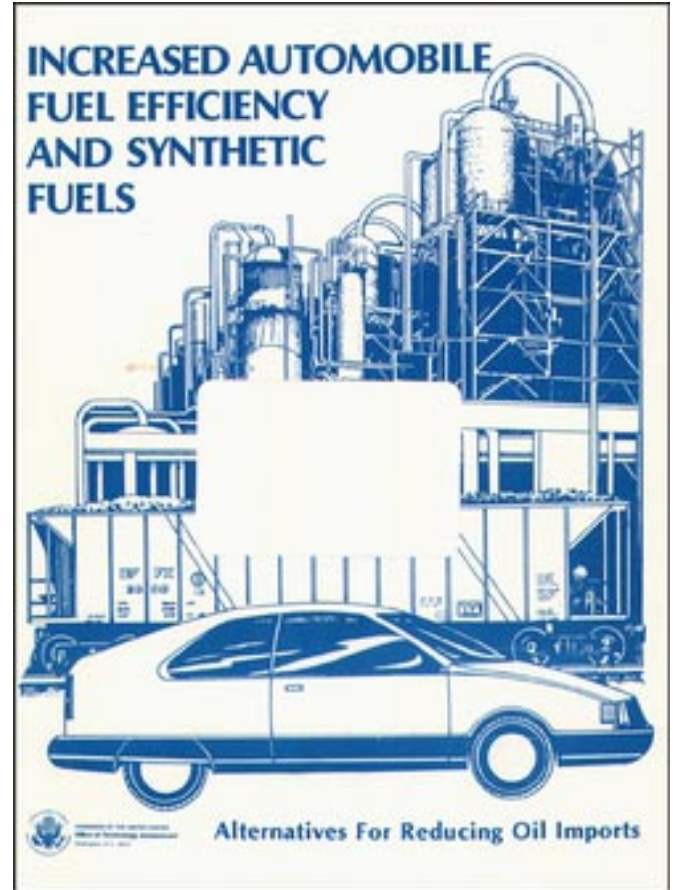*Increased Automobile Fuel Efficiency and Synthetic Fuels: Alternatives for Reducing Oil Imports*

September 1982

NTIS order #PB83-126094

INCREASED AUTOMOBILE FUEL EFFICIENCY AND SYNTHETIC FUELS

Alternatives For Reducing Oil Imports

Foreword

This report presents the findings of an assessment requested by the Senate Committee on Commerce, Science, and Transportation. The study assesses and compares increased automobile fuel efficiency and synthetic fuels production with respect to their potential to reduce conventional oil consumption, and their costs and impacts. Conservation and fuel switching as a means of reducing stationary oil uses are also considered, but in considerably less detail, in order to enable estimates of plausible future oil imports.

We are grateful for the assistance of the project advisory panels and the many other people who provided advice, information, and reviews. It should be understood, however, that OTA assumes full responsibility for this report, which does not necessarily represent the views of individual members of the advisory panels.

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Executive Summary

INTRODUCTION

In 1981, U.S. oil imports averaged 5.4 million barrels per day (MMB/D)–approximately 34 percent of its oil consumption and 15 percent of its total energy use. This is potentially a serious risk to the economy and security of the United States. Furthermore, recovery from the current recession will increase demand for oil and, although currently stable, domestic oil production is likely to resume a steady decline in the near future.

Several options exist for reducing oil imports. However, even with moderate increases in automobile fuel efficiency, moderate success at developing a synthetic fuels industry and the expected reduction in stationary use of fuel oil, U.S. oil imports could still be over 4 MMB/D by 2000, if the U.S. economy is healthy and has not undergone unforeseen structural changes that might reduce oil demand well below projected levels.

Only with vigorous promotion of all three options and technological success can the Nation hope to eliminate oil imports before 2010.

Congress faces several decisions on how to reduce the U.S. dependence on imported petroleum. Two options, increased automobile efficiency and synthetic fuels, are particularly likely to be subjects of congressional debates. First, Congress may want to consider new incentives to increase auto fuel efficiency beyond that mandated by the 1985 CAFE (Corporate Average Fuel Efficiency) standards. Second, Congress will have to decide whether to continue into the second phase of the program to accelerate synfuels development under the Synthetic Fuel Corp. (SFC). The purpose of this report is to assist Congress in making these decisions and comparing these options by exploring in detail the major public and private costs and benefits of increased automobile fuel efficiency and synthetic fuels production. A third option for reducing imports-increased efficiency and fuel switching in stationary (nontransportation) oil uses—is examined briefly to allow an assessment of potential future levels of oil imports. Finally, electric-powered automobiles are examined.

CONCLUSIONS AND COMPARISONS

Import Reductions

In the judgment of the Office of Technology Assessment, increased automobile fuel efficiency, synthetic fuels production, and reduced stationary (nontransportation) use of oil can significantly decrease U.S. dependence on oil imports during the next two to three decades. indeed, reducing oil imports as quickly as possible requires that all three options be pursued. Electric cars are unlikely to play a significant role, however.

Although a precise forecast of the future contributions of the import reduction options is not feasible now, it **is** possible to draw some general conclusions about their likely importance and to estimate what their contributions **could be** under specific circumstances (see fig. 1).

First, **increases in auto fuel efficiency will continue, driven by market demand and foreign**

competition. OTA believes that, with strong and consistent demand for high fuel efficiency, there is a good chance that actual average new-car fuel efficiencies would be greater than OTA's low scenario in which average new-car fuel economy* was projected to be:

30 miles per gallon (mpg) . . . . in 1985
38 mpg . . . ., in 1990
43 mpg . . . ., in 1995
51 mpg . . . . in 2000

with a moderate shift in demand to smaller cars. Although this scenario is based on modest technical expectations, it is dependent on favorable market conditions. Domestic automakers are unlikely to commit the capital necessary to continue

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*EPA values, based on 55 percent city, 45 percent highway. On-the-road fuel economy is expected to average about 10 percent less.

Figure 1 .—Potential Oil Savings Possible by the Year 2000[a] (relative to 1980 demand)
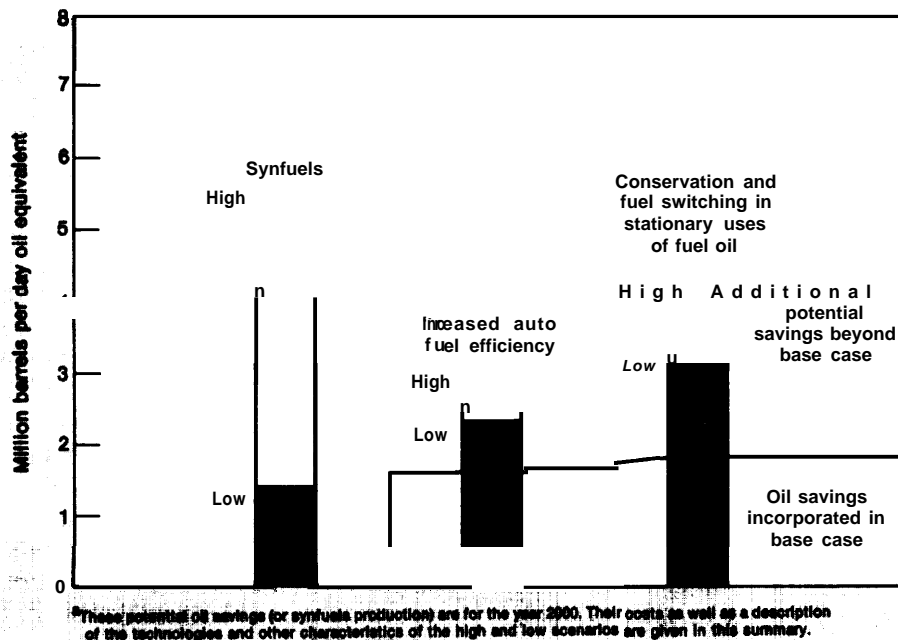
SOURCE: Off Ice of Technology Assessment.

the current rapid rate of increase in efficiency unless they improve their sales and profits.

If the industry is able to attain the fuel efficiency levels shown above, the United States would save 800,000 barrels per day (bbl/d) of oil by 2000 compared with the case where post-1 985 new-car efficiency remained at 30 mpg. The savings would increase to at least 1.1 MMB/D by 2010 because of continued replacement of older, less fuel-efficient automobiles.

With a poorer economic picture and weaker demand for high fuel efficiency, new-car efficiencies could be 40 mpg or less by 2000, with correspondingly lower savings. Achieving 60 to 80 mpg by 2000 would require not only favorable economic conditions and strong demand for fuel efficiency, but also relatively successful technical development.

Second, **substantial contributions to oil import reductions from production of synthetic fuels appear to be less certain than substantial contributions from the other options.** Potential syn-

fuels producers are likely to proceed cautiously for the following reasons: 1) investment costs are very high (even with loan guarantees covering 75 percent of project costs); 2) there is a fairly small differential between the most optimistic of OTA's projected synfuels production costs and the current price of oil; 3) investors are now uncertain about future increases in the real price of oil; and 4) there are high technological risks with the first round of synfuels plants (possibly exacerbated by the cancellation of the Department of Energy's (DOE) demonstration program).

OTA projects that, even under favorable circumstances, fossil-based production of synthetic *transportation fuel* could at best be 0,3 to 0.7 MMB/D by 1990 and 1 to 5 MMB/D by 2000. Biomass synfuels could add 0.1 to 1 MMB/D to this total by 2000. In less favorable conditions—for example, if the SFC financial incentives were withdrawn—it appears unlikely that even the lower fossil synfuels estimate for 1990, and perhaps 2000, could be achieved unless oil prices increase much faster than they are currently expected to.

Achieving much more than 1 MMB/D of synfuels production by 2000 would require fortuitous technical success and either: 1) unambiguous economic profitability or 2) continued financial incentives requiring authorizations considerably larger than those currently assigned to SFC. Achieving production levels near the upper limits for 2000 are likely to be delayed, perhaps by as much as a decade, unless there is virtually a "war mobilization' '-type effort.

Third, **there are likely to be large reductions in the stationary use of fuel oil (currently 4.4 MMB/D) in the next few decades.** With just cost-effective conservation measures, stationary fuel oil use could be reduced significantly. Additional conservation measures by users of electricity and natural gas could make enough of these fuels available to replace the remaining stationary fuel oil use by **2000.** Total elimination of stationary fuel oil use by **2000** is unlikely, however, because site-specific factors and differing investor payback requirements will mean that a significant fraction of the numerous investments needed for elimination will not be made.

Fourth, **even a 20-percent electrification of the auto fleet—a market penetration that must be considered improbable within the next several decades—is unlikely to save more than about 0.2 MMB/D.** Electric cars are most likely to replace small, low-powered–and thus fuel-efficient —conventional automobiles, minimizing potential oil savings.

Plausible projections of domestic oil production —expected by OTA to drop from 10.2 MMB/D in 1980 to 7 MM B/D or lower by 2000—suggest that oil imports could still be as high as 4 to 5 MM B/D or more by 2000 unless imports are reduced by a stagnant U.S. economy or by a resumption of rapidly rising oil prices. * Achieving low levels of imports-to perhaps less than 2 MM B/D within 20 to 25 years–is likely to require a degree of success in the three major options that is greater than can be expected as a result of current policies.

costs

Except for stationary fuel oil reductions, economic analysis of the options for reducing oil imports involves a comparison of **tentative** cost estimates for mostly **unproven** technologies that will **not be deployed for 5 to 10 years or more.** Even if costs were perfectly estimated for today's market (and the estimates are far from perfect), different rates of inflation in the different economic sectors affecting the options could dramatically shift the comparative costs by the time technologies are actually deployed. Figure 2 presents OTA's estimates for the investment costs for all options except electric cars. The costs are expressed in dollars per barrel per day, which is the amount of investment needed to reduce petroleum use at a rate of 1 bbl/d. * In OTA's judgment, **the estimated investment costs (in dollars per barrel per day) during the** 1990's **of automobile efficiency increases, synthetic fuels production, and reduction of stationary uses of oil are essentially the same, within reasonable error bounds. If Congress wishes to channel national investments preferentially into one of these options, differentials in estimated investment costs cannot provide a compelling basis for choice.**

On the other hand, **investments during the 1980's to reduce stationary oil use** (from the current 4.4 to 3 MM B/D or less by 1990) **and increase automobile fuel efficiency** (to a 35 to 45 mpg new-car fleet average by 1990) **are likely to cost less than the 1990-2000 investments in any of the options.**

Electric vehicles are likely to be very expensive to the consumer—costing perhaps $3,000 more per vehicle than similar, conventional automobiles or $300,000 to $400,000/bbl/d of oil saved, (The latter is not strictly comparable to investment costs for the other options.) If batteries must be replaced at moderate intervals, which is necessary today, the total costs of electric cars would escalate.

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*Rapidly rising oil prices are unlikely to occur simultaneously with a stagnant U.S. economy unless the economies (and oil import requirements) of Europe and others are thriving at the same time.

*This measure was chosen in order to avoid problems that arise when comparing investments in projects with different lifetimes and for which future oil savings may be discounted at different rates.

Figure 2.—Estimated Investment Costs for the Oil Import Reduction Options
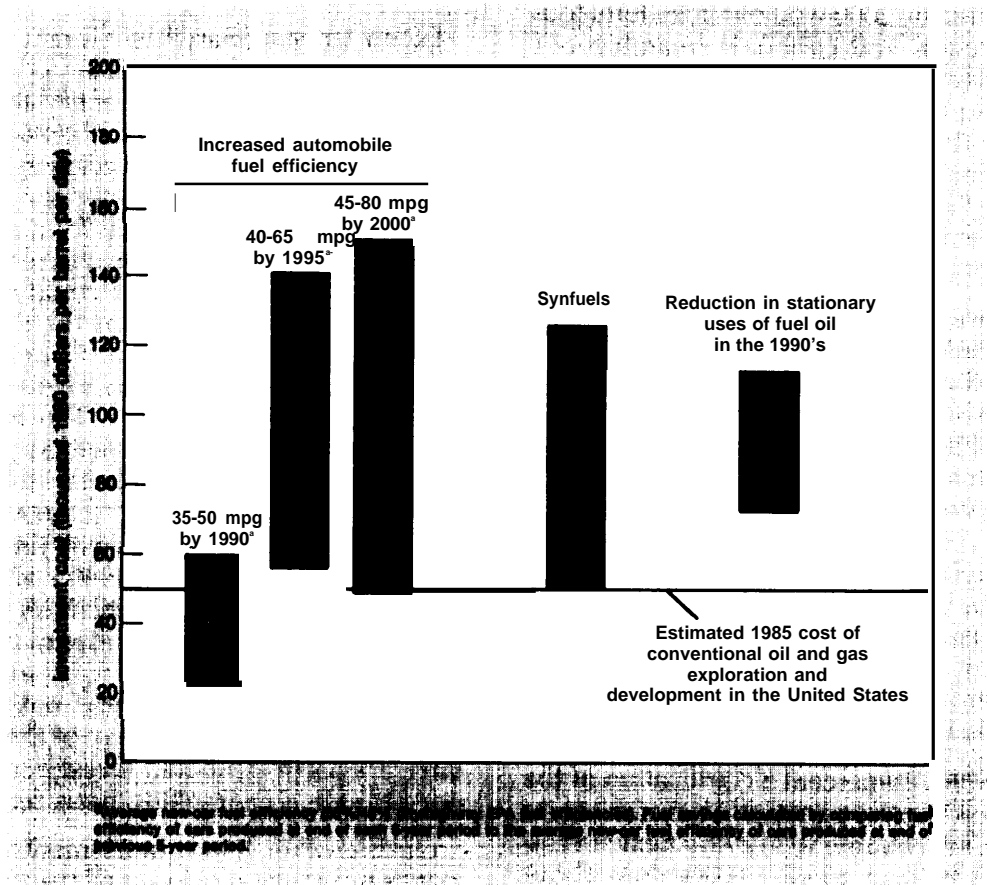
SOURCE: Office of Technology Assessment.

Technological and Economic Risks

The general perception of the technological and economic risks of the import reduction options is: 1) that the reduction of stationary oil use has comparatively predictable costs and few technological risks; 2) that synthetic fuels have severe economic and technological risks; and 3) that increased auto fuel efficiency has moderate economic and technological risks. OTA's analysis indicates that these perceptions are correct only to a limited extent.

Ž Although the costs and technology of fuel switching are well known and involve little risk, the success of retrofitting a given building to increase its energy efficiency often cannot be accurately predicted because of site-specific considerations that cannot be adequately quantified.

- The differences in risks between synfuels development and increased automobile fuel efficiency are less a matter of overall magnitude than of timing.

- Synfuel production involves considerable technical and economic risks for the first round of commercial-scale facilities, but once full-scale process units have been demonstrated the risk for future plants should drop substantially.

- Some increases in automobile fuel efficiency can be implemented with negligible technological and small economic risks, but increases to very high efficiencies do involve significant

technical and economic risks. Also, as the number and rate of changes in automobiles increases, there is increased risk that consumers will not accept the automobiles and that insufficient development and testing will lead to poor on-the-road performance and/or product recalls.

Additional Bases for Comparison— Environmental, Social, and Economic Effects

Increased auto fuel efficiency may reduce vehicle safety as cars are made smaller and lighter. But in all but extreme cases of vehicle size reduction, improvements in vehicle design and increased passenger use of safety restraints have the potential to offset any effects of reduced size and weight on the vehicle's protection of its occupants in a crash.

Continued pressure for increased fuel efficiency will dictate new plant investments which will reinforce the ongoing restructuring of the U.S. auto industry. This restructuring involves a shift in manufacturing away from the traditional production centers to the Sun Belt and overseas, and stronger industry ties with foreign manufacturers. The composition and size of the manufacturing work force may evolve towards a greater proportion of skilled workers but fewer workers overall. Increased sophistication and capital investment may be required for vehicle maintenance. A reduction in the number of suppliers to the auto industry may also result.

Large-scale synthetic fuels production would generate significant amounts of toxic substances, posing risks of health damage to workers and possible risks to the public through contamination of ground waters or by small amounts of toxics left in the fuels. There should not be any technological barrier to adequate control of these substances, but OTA concludes that there are substantial reasons to be concerned about the adequacy both of proposed environmental protection systems and of the existing regulatory structure.

Other important effects of synfuels production stem from the very large scale of both the individual projects and, potentially, the industry as a whole. These may overwhelm the social and economic resources of nearby population centers, especially in sparsely populated areas of the West. At national production levels of a few million barrels per day, impacts from coal and shale mining and population pressures on wilderness areas and other fragile ecosystems can be substantial even in comparison with major industries such as coal-fired power generation. On the other hand, conventional air pollution problems from such plants are likely to be considerably less than those associated with similar amounts* of coal-fired power generation.

Finally, although water requirements for synfuels are a small fraction of total national consumption, **growth of a synfuels industry could either create or intensify competition for water, depending on both regional and local factors.** Such competition is of special concern in the arid West. Unfortunately, a reliable determination of both the cumulative impacts on other water users and, in some instances, the actual availability of water for synfuels development is precluded by physical and institutional uncertainties, changing public attitudes towards water use priorities, and the analytical shortcomings of existing studies.

However, in areas where there are relatively few obstacles to transferring water rights (e.g., as is currently the case in Colorado), developers should be able to obtain the water they need because their consumption per barrel of oil produced is small enough to enable them to pay a relatively high price without significantly affecting the final cost of their products.

Electric vehicles, if they are ever produced in large quantities, could have an important positive environmental effect-the reduction of automobile exhaust emissions and resulting improvements in urban air quality.

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*On a "per unit of coal used" basis.

POLICY

OTA's analysis points to two conclusions that may warrant congressional consideration of changes in current Federal energy policy.

First, current policies affecting investments in energy conservation and domestic energy production are not likely to result in levels of oil imports below 4 MMB/D in 2000, if the U.S. economy is healthy and has not undergone unforeseen structural changes that might reduce oil demand well below projected levels. During the next **20** years, OTA expects that, under these policies, oil import reductions due to synthetic fuels production and decreased stationary and automobile oil use will be partially offset by a decrease in domestic production of conventional oil. Reducing net oil imports to 1 or 2 MMB/D or less by 2000 is likely to require more vigorous pursuit of all options for reducing domestic consumption of conventional oil products. On the other hand, elimination of current conservation and synthetic fuels production policies could cause imports to range from **5** to **6** MMB/D by 2000 under these same economic conditions.

Second, current policies may not provide society with adequate protection from some of the adverse side effects of synthetic fuels development and increased automobile fuel efficiency. Of particular concern are possible reductions in automobile crash safety (as the number of smaller, more fuel-efficient cars increases), inadequate control of toxic substances from synfuels development, and adverse socioeconomic effects from both options.

Because of the large technical, economic, and market uncertainties inherent in the analyses of oil displacement options, Congress may wish to emphasize flexible incentives with provisions for periodic review and adjustment. A stable commitment to oil import displacement will be necessary, however, to maximize the effect of such policies.

Stimulating Oil Import Reductions

The level of oil imports at the turn of the century will be determined by market forces, modified by Government policy towards oil supply and demand. The imposition of Federal policy on the workings of the private market generally is justified on the basis of the market's failure to value public costs and benefits. A particularly important public cost of U.S. dependence on imported oil, for example, is the national security problem imposed by political instability in the Middle East and the resulting potential for oil cutoffs. Although the precise magnitude of these costs is debatable, most people would agree that they are significant ($5 to $50/bbl depending on various circumstances) and that the private market generally does not take them into account.

Efforts to displace imports also have both public and private costs. In addition to the potential side effects just mentioned, Government interference in the oil marketplace can cause significant misallocations of resources. Congress will have to balance costs and benefits, which cannot be reduced to common measures and which change with time, in a complex tradeoff.

One policy option to displace imports is an energy tax, either on oil imports or on oil in general. Both taxes have the advantage of encouraging alternatives to conventional oil consumption without predetermining which adjustments would be made. They could be used to provide consistent price signals to the market—to assure the auto industry, for example, that demand for fuel-efficient cars would continue and to assure synfuels developers that they would receive at least a constant real price for their products. imposing a tax only on transportation fuels would send the same signal to both the auto industry and to producers of synthetic transportation fuels, but this preferential treatment would be at the expense of other conservation or synfuels production investors.

All of these petroleum taxes also have a number of other effects which must be considered. For example, a tax only on oil imports leads to an income transfer from domestic oil consumers to domestic oil producers; and all oil taxes can lead to reduced international competitiveness of domestic industries heavily dependent on oil, such as the petrochemical industry.

policies can also be directed specifically at the automobile or synfuels industries. The most effective of these options will be those that directly address the factors that shape, direct, and limit the contributions that the automobile and synfuels industries can make to import displacement.

The critical factors that determine the pace of **increased automobile fuel efficiency** are consumer demand for fuel efficiency and the financial health of the domestic auto industry. If the industry is uncertain about demand, it will be reluctant to make the expensive investments. And with continued poor sales, the industry will be less able to afford them.

Aside from energy taxes, Congress can maintain and stimulate consumer demand for fuel efficiency by a variety of measures that would raise the relative costs to consumers of owning inefficient cars. For example, registration fees (one time or annual) and purchase taxes or subsidies are incentives that can be directly linked to fuel efficiency. However, fuel-efficiency incentives that do not discriminate with respect to car size would tend to increase sales of small cars at the expense of larger cars. Such discrimination might hurt domestic manufacturers, which have been most vulnerable to foreign competition in the small-car market.

Congress can also choose policies aimed at auto production such as continuing to require manufacturers to improve fuel efficiency by means of stricter CAFE or similar standards that would ensure increased fuel efficiency even if demand for this automobile attribute is low. This regulatory route might reduce some risks to automakers by requiring all to make similar investments. On the other hand, car sales may suffer if the costs of the fuel savings—either in higher sticker prices or reductions in some desirable vehicle attributes–are higher than consumers are willing to pay. Fuel-economy requirements are likely to be perceived by the industry as exceedingly risky unless the requirements are accompanied by measures to stimulate demand or to ease the resulting financial burden on the automakers.

To help ensure that the fuel-efficient cars are actually bought and that the automakers can ac-

quire the capital needed for increasing fuel efficiency, Congress may also wish to directly promote sales of fuel-efficient cars. A low-interest-rate loan program (with interest rates tied to fuel efficiency) is one potentially effective mechanism. Congress may also wish to consider awarding direct grants or loan guarantees for qualifying investments in auto manufacturing facilities.

The factors that determine the pace of **synfuels development** are the high degree of technical uncertainty and the continuing uncertainty about future oil prices. Both areas of uncertainty contribute to doubts about profits.

Current Federal policy maintains the valuable incentives associated with SFC, but reemphasizes DOE's research, development, and demonstration programs. The loan guarantee mechanism offered by SFC significantly improves the probability of financial success for a developer and probably will be necessary to ensure even a few hundred thousand barrels per day of synfuels production by the early 1990's. Several major risks to synfuels investors remain, however. Cost overruns could nullify any potential profits because developers must base their product prices on the market prices of competing fuels rather than on synfuels production costs. It is also probable that several first generation commercial-scale units will function poorly, and rapid expansion of the industry may thereby be delayed.

Since the SFC program appears to be attracting the capital needed to build and demonstrate a series of first generation commercial-scale production units, cancellation of DOE's programs may not turn out to be particularly harmful to synfuels development **if the first plants perform well.** However, cancellation of the demonstration program probably will mean that fewer technologies reach the stage where SFC support is possible. Reemphasis of development programs may also delay findings that would be useful in fixing the technical problems that are likely to arise in the first commercial-scale units. To hedge against the possibility of poor operation delaying expansion, Congress may wish to support development programs intended to demonstrate the technical feasibility of a variety of processes and to gain basic knowledge of and experience with

these processes. Although these demonstration programs support second and third generation processes, they will also provide engineering information that may be useful for correcting technical faults and reliability problems that may arise in first generation plants.

Dealing With Other Effects

An important effect of increasing automobile fuel efficiency is the potential for decreased automotive safety due to size and weight reduction. There may also be major employment-related side effects associated with the restructuring of the auto industry and the accompanying accelerated rates of capital investment by the industry. There are familiar policy instruments that can deal with both of these effects. For the safety effects, Congress can choose among safety standards for new cars, educational programs, and support of safety R&D. Employment effects may be eased by minimizing plant relocations (through tax breaks or direct assistance to the industry), or by ameliorating the effects of employment reductions through aid to communities and affected workers and other individuals.

potential environmental and worker-related problems associated with synfuels development are substantial, and there is cause for concern about the adequacy of future regulation of the synfuels industry. The Government can help to assure that the private sector takes account of these problems. Specific areas worthy of congressional attention include: the environmental research and regulatory programs of the Environmental Protection Agency (EPA), DOE, the Office of Surface Mining, and the Occupational Safety and Health Administration, in light of recent budget cuts and changes in program direction; the dismantling of DOE's demonstration program for synfuels technologies; and the progress of SFC in demanding appropriate consideration of siting, monitoring, pollution controls and occupational safety as a condition for financial assistance. Congressional options range from holding oversight hearings to increasing the resources of the environmental regulatory agencies and shifting their program emphases by legislation.

To mitigate the socioeconomic effects on communities from synfuels development, Congress may wish to consider several forms of growth management assistance, including loan guarantees, grants, and technical assistance. Any new Federal initiatives in this area will be complicated, however, by continuing arguments about relative responsibilities of Federal, State, and local governments and private industry. And new initiatives need to be sensitive to the substantial differences from location to location in the severity of impacts and the resources already available for mitigation.

OVERVIEW OF THE IMPORT REDUCTION OPTIONS

Increased Automobile Fuel Efficiency

Automobile fuel efficiency can be increased through a variety of measures, including:

- reductions in vehicle weight;
- improvements in conventional engines, transmissions, and lubricants;
- better control of engine operating parameters;
- new engine and transmission designs;
- reduced aerodynamic drag;
- improvements in accessories; and
- decreases in rolling resistance.

Projections of Fuel Economy

Future oil savings from increased automobile fuel efficiency depend, first, on the magnitude and character of future auto sales. In the past few years, consumer preferences for such fuel-economy-related characteristics as vehicle size and performance have fluctuated while new car sales have dropped significantly. Both the long-term sales average and consumer preference for fuel efficiency will be critical determinants of the rate of penetration of fuel efficiency technology.

Second, in response to changing consumer preferences and foreign competition, the rate of

change of vehicle technology has accelerated and old rules about how long it takes to put a new technology into place* are no longer valid. The present rapid rate of replacement of capital equipment puts a great strain on the domestic auto industry. During the next several years, competitive forces will push toward continued rapid technological change, but the financial weakness of the domestic auto industry will pull toward slower technological change. The strength of future foreign competition and consumer perceptions of the future price and availability of gasoline and diesel fuel, among other factors, will influence the balance of these opposing forces, and, consequently, whether rapid increases in fuel efficiency of domestically produced cars continue.

Third, the efficiency increases are not fully predictable. There can be discrepancies between test results and the results obtained in actual use. Technical compromises that affect ultimate performance have to be made to allow better integration with existing equipment, easier and cheaper production and assembly, and resistance to extreme operating conditions and incorrect maintenance procedures. Development problems are not always solved satisfactorily; such problems could occur more frequently if technological change accelerates.

OTA developed projections (table 1) of plausible ranges of average new-car fuel economy based on varying expectations of the relative demand for different-sized cars and the effectiveness and rate of development and introduction of new fuel-economy improvements. As reflected in these projections, both technology and vehicle size are critical factors for future fuel savings. Marketplace uncertainty is reflected even as early as the 1985 projections—manufacturers' plans and the technology are already established, but the

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*For example, previous assumptions were: 5 years to move from initial production decision to introduction of a technology in a model line; 5 to 10 years to diffuse the technology throughout the new car fleet; and 10 to 15 years of production to pay for the investment. The estimate of 5 years to move from initial production decision to introduction may now be a bit too low, while increased rate of change of vehicle technology would necessarily reduce the other two estimates.

Table 1.- Projected Average New-Car Fuel Economy,[a] 1985.2000 (mpg)

	1985	1990	1995	2000
No further shift towards smaller cars beyond 1985	30-34	36-45	39-54	43-62
Moderate further shift to smaller cars	30-34	38-48	43-59	51-70
Rapid shift to small cars	33-37	43-53	49-65	58-78

[a] Based on EPA city/highway (55/45 percent) cycle. Each of the mileage ranges (e g., 3034) reflects relative expectations of the performance and rate of development and deployment of new technologies. The lower value represents OTA's "low estimate" scenario, the upper value represents a "high estimate" scenario.

SOURCE: Office of Technology Assessment

Note on Table 1: Can We Do Better?

The projections in table 1 do not represent the *technological* limit of what could be achieved in this century. The most efficient automobiles in each size class are likely to achieve considerably better fuel economy than the average; for example, technologies are available that probably can allow a new-car fleet average of 60 mpg by the mid-1990's with the same mix of vehicle sizes as today's and adequate vehicle performance (compared with the table's 1995 "same size mix" projection of 39 to 54 mpg). *This ignores consumer preferences for vehicle features that conflict with fuel economy maximization, however.* By the same argument, the 1981 new-car fleet average *could have been 33* mpg if consumers had consistently chosen the most efficient vehicle in each of the nine EPA size classes and producers had been able to meet the demand. Instead, the actual 1981 model average to January 1981 was 25 mpg.

Interestingly enough, if consumers had chosen only the most fuel-efficient gasoline-powered automobiles in each size class, over 90 percent of the vehicles would have been U,S.-manufactured cars or captive imports. The market problems of U.S. manufacturers in 1981 cannot be traced primarily to an inability of U.S. manufacturers to produce fuel-efficient cars, but depend on factors such as differences in perceived value between American and imported automobiles.

The difference between *average fuel efficiency,* which is a function of consumer preference, and *potential fuel efficiency,* which assumes that every car in the fleet embodies the most fuel-efficient choice of technologies available, is critical to understanding why OTA's projections may differ from other projections that apply a single choice of technologies to the entire fleet. The latter assumption is realistic only if future consumers value fuel economy, relative to other automobile attributes, much higher than they do today.

projections still range from 30 to 37 mpg* (compared to the 1981 level of 25 mpg).

How much fuel can be saved by improved fuel economy? Assuming 30 mpg as a base and using the projections in table 1, **continued developments in automobile fuel efficiency could save 0.6 to 1.3 MMB/D of oil by 2000.** The lower value represents pessimistic expectations about the advance of automobile technology and the shift towards smaller cars; the higher value represents optimistic technological expectations and continued substantial shifts to small cars. **Contin-**

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* Based on a weighted average of 55 percent EPA city test cycle and 45 percent EPA highway cycle, the formula used to measure compliance with currently mandated CAFE requirements.

ued diffusion of these technologies into the overall fleet could save 0.8 to 1.7 MMB/D by 2010 with no further technological advances beyond 2000. *

costs

OTA's cost analysis of auto fuel-efficiency improvements concentrates on investment costs in total dollars as well as dollars per barrel per day of oil saved. Estimates of the costs for associated technology and product development are included in the investment costs,** because **they** are part of the normal outlays needed to put any new vehicle in production and represent a sizable fraction of the fixed costs (i.e., costs independent of production levels).

It is not possible to make highly accurate estimates of the investment costs (per barrel per day of oil saved), due to the uncertainty associated with predicting actual efficiency increases that will be achieved. In addition, the cost of developing technologies to the point where they can be reliably mass-produced has been highly variable and is difficult to predict.

Accurate cost estimation also is complicated by the difficulty of separating the cost of increasing fuel efficiency from the other costs of doing business. Increases in fuel efficiency are inextricably intertwined with other changes in the car. For example, the engine redesign for fuel efficiency may incorporate other changes, to improve other automobile attributes, at little additional cost. Design changes that increase efficiency may improve or degrade other attributes such as emissions or performance.

If it is the industry's judgment that consumers do value fuel efficiency, the normal cycle of capital turnover and vehicle improvement would result in an increase in fuel efficiency automatically. Unfortunately, the "normal" rate of fuel efficiency increase is not really predictable because

it depends on marketplace preferences and corporate strategies.

Because of the difficulty of separating out the marginal fuel efficiency investments from the "normal" investments, OTA's investment cost estimates (in dollars per barrel per day) in table 2 are the **total** investments (including development costs) **allocated to increasing fuel efficiency,** divided by the total fuel savings rate expected. (See footnote c of table 2 for the details of the cost al location.) These investment rates may be somewhat lower than the marginal rates would be because, in designing their "normal" investment programs, manufacturers probably will select those investments with the highest potential payoff in efficiency increase per dollars spent.

In any case, the range of investment rates for increased fuel efficiency for each time period overlap the rates for investments in synfuels plants (see Synthetic *Fuel* section below), although the 1985-90 fuel-efficiency rates would be lower than the synfuels rates if widespread expectations for overruns in early synfuels investments are proved correct,

The total domestic capital investment associated with increased fuel efficiency would be about $25 billion to $70 billion between 1985 and 2000, or less than $2 billion to $5 billion annually during the period. This level of investment can be compared with recent and projected capital investment by the industry* remembering that part of the fuel-efficiency investment could be included in "normal" capital expenditures if consumer demand for fuel efficiency is high enough. For the period 1968-77, annual capital investment by General Motors (GM), Ford, and Chrysler averaged $6.68 billion in constant 1980 dollars. Investments by these companies rose to $10.4 billion in 1979 and $10.8 billion in 1980, and are projected by some analysts to rise to $12 billion per year during 1980-84. The ability of the domestic industry to maintain their expected schedule of capital expenditures is dependent on

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*Assuming 1.26 trillion vehicle miles (automobile only) traveled annually in 2000, 1.31 trillion in 2010, and an on-the-road fuel efficiency 10 percent less than EPA rated fuel efficiency.

**In this context, development means all of the engineering activities needed to prove a design concept and determine how it can best be integrated into the vehicle system and mass-produced.

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*The two sets of figures are not fully analogous. A portion of the domestic industry's costs are for overseas investments, while a portion of the 1985-2000 fuel efficiency costs will be borne by outside suppliers rather than the major manufacturers.

Table 2.—Domestic³ Investment for Increased Fuel Efficiency

Time	Car sales (mill ion/yr)	New-car fuel efficiency (mpg)ᵇ	Efficiency investment (thousand 1980 $/bbl/day)	Total investment (billion 1980$ during time period)
1985-1990	8.6	38-48	20-60	8-29
1990-1995	8.8	43-59	60-140	9-20
1995-2000	9.1	51-70	50-150	7-18

ᵃAssumes 75 percent of all cars sold are manufactured domestically.
ᵇFleet average miles per gallon at end of time period, with moderate shift in demand to W?' Idler cars,
ᶜRepresents costs allocated t. fuel efficiency, including associated development costs of 40 percent of capital spending. Investment was allocated in the following way: 50 percent of the total engine investment is assumed to be for fuel efficiency; 75 percent of the total investment for conventional transmissions is for fuel efficiency; and all of the investment for advanced materials substitution, automatic engine on/off, and energy storage devices is for fuel efficiency.
ᵈIncludes all capital costs associated with fuel efficiency, including fraction allocated to other attributes, but excluding development costs,

SOURCE: Office of Technology Assessment.

a resumption of their former levels of sales and profitability. There are already signs that U.S. auto manufacturers are beginning to cut back on planned investments in the face of continued poor sales and declining cash reserves.

If consumer demand for fuel efficiency is consistently strong, domestic manufacturers are likely to respond by **at least** incorporating into their "normal" * rate of capital turnover as many fuel-efficiency features as possible. if capital turnover is limited to its historical "normal" rates, then the fuel efficiencies shown in table 1 could still be achieved, but it would take longer to implement the changes than is indicated by the schedules shown in that table. In particular, implementation of the low scenario could require **25** percent longer (relative to 1985) than the schedule in table 1; and the high scenarios could require 45 percent longer. Whether the high or the low scenario is eventually achieved, however, also depends on the success of technical developments.

If demand for fuel efficiency were high enough, however, the manufacturers would increase their redesign/replacement rates. By adding $5 billion to $10 billion in capital expenditures during 1985-2000, or $0.3 billion to $0.7 billion per year (5 to 10 percent above "normal"), capital turnover can be speeded up to allow the low scenarios to be achieved on the schedule in table 1. Similarly, if technology developments are successful, the high scenario could be achieved as shown in table 1 with capital expenditures of $9

billion to $23 billion above "normal" during the period 1985-2000, or $0.6 billion to $1.5 billion per year (10 to 20 percent above "normal").

If future demand for fuel efficiency is not high enough to support these rates of change, increases in fuel efficiency will be further delayed unless required by new CAFE standards. On the other hand, CAFE standards **without** analogously high consumer demand for efficiency would require the manufacturers to either defer expenditures for other improvements that might help car sales or to incur additional capital costs.

The consumer costs of increased fuel efficiency, measured in dollars per gallon of gasoline saved, are speculative because the variable costs —mostly material and labor costs—are even more difficult than investment costs to determine accurately. OTA's analysis is based on alternative assumptions about the degree of change in material and labor costs. A direct calculation of these costs would have been expensive and the results difficult to defend because the source data is proprietary and highly dependent on judgments about the success of adapting technologies to mass production. Table 3 shows the range of costs attributed to fuel efficiency assuming that consumers value future gasoline savings as highly as today's savings (i.e., without discounting future savings*) and that manufacturers pass through the full costs. Conceivably, foreign competition could force the manufacturers to absorb part of these costs.

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*Assuming "normal" capital turnover is: engines improved after 6 years, on average, redesigned after 12 years; transmissions same as engines; body redesigned every 7.5 years; no advanced-materials substitution.

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*The cost perceived by consumers would be about 2.5 times as high as those shown if the consumer discounts future fuel savings at 25 percent per year, i.e., each future year's savings during the life of the car is valued at 25 percent less than the previous year's savings.

Table 3.—Consumer Costs for Increased Automobile Fuel Efficiency, Without Discounting Future Fuel Savings, Moderate Shift to Smaller Cars

Time period	Average new-car fuel efficiency at end of time period (mpg)	Consumer cost[a] ($/gal saved)	
		No variable cost increase	High variable cost[b] increase
1985-1990	38-48	0.15-0.40	0.40-1.10
1990-1995	43-59	0.35-0.85	1.10-2.60
1995-2000	51-70	0.30-0.95	0.90-2.80

[a]Assumes a capital recovery factor per year of 0,15 times the capital investment allocated to fuel efficiency
[b]Assumes variable cost increase is twice the capital charges associated with the capital investments allocated to fuel efficiency.

SOURCE: Office of Technology Assessment.

The consumer costs of fuel efficiency range from values that are easily competitive with today's gasoline prices to values that are considerably higher, depending on the efficiency gains actually achieved, the success of developing production techniques that can hold down variable cost increases, and the value consumers place on future fuel savings. Investments for increased efficiency for the 1990-2000 model years will look particularly risky if the current soft petroleum market continues for a few more years, or if auto manufacturers have difficulty holding down their labor and materials costs.

Another important measure of the cost to consumers of increased fuel efficiency is the increase in the price of new cars required to recover the industry's increased production costs. If the market demand for fuel efficiency is strong enough to ensure that as much as possible of the capital investment for fuel efficiency increases is incorporated into the normal capital turnover, and if the variable costs of production can be held constant, then the cost* of achieving OTA's fuel-efficiency scenarios can be as low as $60 to $130 per car during the 1985-2000 time period. Under these conditions, an average of 35 to 45 mpg could be achieved by 1990 without increasing new-car costs.

If actual market demand for fuel efficiency is not this high, automakers would be unlikely to incorporate a very high level of fuel efficiency investments into their normal capital turnover. Also, the variable costs of production **are** likely to rise somewhat. The "upper bound" for added costs —assuming large increases in variable costs and

no market-driven investment for fuel efficiency increases beyond 1985—is **$800** to **$2,300** per car during the 1985-2000 period, and $250 to $500 per car to achieve 35 to 45 mpg by 1990. Therefore, the cost per car of increased fuel efficiency beyond 1985 ranges from "clearly competitive" to "probably unacceptable. "

Economic Impacts

The domestic automobile industry is in the midst of a massive investment program aimed at improving the competitiveness of American automobiles. These expenditures are associated with important structural changes in the industry; and accelerating the rate of capital turnover (for increased fuel efficiency or other reasons) may accelerate some of these trends.

Manufacturers are closing older, inefficient plants and building new ones that incorporate extensive use of robots and other labor-saving technology to increase productivity. For a number of reasons, including lower labor and other costs, many of the new facilities may be built in the Nation's Sun Belt or overseas rather than in the current North-Central auto manufacturing centers, although recent labor concessions may change this picture. Because of a shift in U.S. demand to smaller cars, which can be marketed more universally, the incentive to produce in the United States is diminishing. Finally, because rapid capital turnover is raising production costs at a time when consumer demand for automobiles has been sluggish, manufacturer profits have diminished and it has become harder for the firms to secure capital at affordable costs.

American companies are forging more extensive ties with foreign manufacturers to design,

*Assumes a capital recovery factor of 0.15.

produce, and market fuel-efficient cars, and are moving towards producing more nearly standardized automobiles that can compete in international markets. Current trends seem to be toward fewer separate automotive manufacturing and supply firms worldwide; only GM and Ford appear to be reasonably certain of remaining predominantly American-owned.

Certain regions such as the industrial Midwest —and the Nation as a whole—will lose jobs if these structural changes continue. Job losses also would occur, however, if the process is interrupted, because the restructuring represents the industry's response to the conditions that caused its present market problems, and it clearly is aimed at regaining sales.

Social Impacts

As auto manufacturing and supply activities become more efficient and automated, there will be important changes in the workplace environment. Robots and other automated equipment will increasingly be used for the more routine and dangerous jobs, and skilled workers such as engineers and maintenance technicians should become a greater percentage of the smaller total work force. Shifting manufacturing overseas will reduce U.S. employment in primary manufacturing as well as in supplier companies. Although employment losses may be larger in the supplier industries, the effects in these industries will be distributed over a larger geographical area. Employment in related activities such as repair and service will change to accommodate the new auto characteristics—e.g., repairs of plastic body components require adhesives, not welding—and the increasing sophistication and capital investment required for vehicle maintenance will place new demands on shops and dealers.

Fuel efficiency increases also affect automobile owners by changing the physical attributes of the vehicle and the economics of owning cars. For example, a continued reduction in car size could lead to increasing use of rentals for longer trips or for occasional requirements for increased cargo-carrying capacity. Increases in the initial cost of buying a car are likely to lead to a continuation of current trends of keeping cars longer,

resulting in a slower growth or reduction in new-car sales.

Environment, Health, and Safety

Increasing automobile fuel efficiency appears likely to have a relatively benign effect on the natural environment and public health, because most of the efficiency measures have few adverse effects on auto emissions, emissions associated with vehicle manufacturing, etc. An important exception may be any shift to widespread use of diesel engines, which could cause problems with vehicle particulate and nitrogen oxide (NO_x) emissions. Also, the increased production of lightweight materials—particularly aluminum—may cause additional impacts, such as increased energy consumption in processing and increased demand for bauxite. On the other hand, significant downsizing of automobiles could allow either lower vehicle emissions or lower control costs to maintain current emission levels.

In contrast to their expected small effect on pollution levels, fuel conservation measures that stress reducing vehicle size may have a significant adverse effect on vehicle safety. This is because of the important role in crash survival played by "crush space"* and other size- and weight-related factors. Even a relatively small decline in vehicle safety could cause hundreds or even thousands of additional deaths and serious injuries per year.

There is no widely accepted estimate of the magnitude of this effect. The National Highway Traffic Safety Administration has projected a 10,000 per year increase in traffic deaths from vehicle size reductions by 1990, but this is based on a limited data set and a number of simplifying assumptions. And a net increase in traffic deaths is not inevitable, since increased usage of passenger restraints and improvements in vehicle design could more than offset the effect of moderate size reductions.

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*With a smaller "crush space" (thus, more rapid *deceleration* of occupants in a crash), factors such as seatbelt and shoulder restraint usage, better driver training and traffic control, and other safety measures, become more important determinants of traffic safety.

Synthetic Fuels

Production of a variety of fossil fuel-based synthetic fuels is planned or under development.

● Oil shale can be heated to release a liquid hydrocarbon material contained in the shale. After further upgrading a **synthetic crude oil** similar to high-quality natural crude oil can be produced. This can be refined into gasoline, diesel and jet fuels, fuel oils, and other products.

● Coal can be partially burned in the presence of steam to produce a so-called "synthesis" gas of carbon monoxide and hydrogen, from which **gasoline, methanol, diesel and jet fuel, and other liquid fuel products** ("indirect liquefaction") or **synthetic natural gas (SNG)** can be produced.

● Coal also can be reacted directly with hydrogen (which is itself generated from a reaction of steam and coal) to produce a **synthetic crude oil** ("direct liquefaction"). This oil can be converted to **gasoline, jet fuel and other products** in specially equipped refineries.

Projection of Synfuels Development

The principal technical deterrent to rapid deployment of a synfuels industry is the lack of proven commercial-scale synfuels processes in the United States. Shale oil, indirect coal liquefaction, and SNG processes currently are sufficiently developed that the demonstration of commercial-scale process units or modules is being pursued, but these first units are likely to require considerable modification before they can operate satisfactorily. Once these commercial-scale modules have been adequately demonstrated, full-size commercial facilities can be constructed (from several modules). in contrast, direct coal liquefaction requires further development before commercialization and probably will not contribute significantly to the synfuels industry before the mid to late 1990's. A major technical obstacle, the handling of high levels of solids in the process streams, is not now understood well enough to allow developers to move directly to commercial- from small-scale units now in operation.

Normal planning, permitting, and construction may take 7 to 8 years for a large synfuels plant, with the last 5 years or so devoted to construction. Consequently, a first round of commercial-scale plants conceivably could be operating by the late 1980's, although these would be quite vulnerable to delays and cost overruns. Beginning a second round of construction before the first set of plants has been fully demonstrated would risk additional costly revisions and delays.

In addition to scheduling constraints caused by technological readiness, shortages of experienced manpower (primarily chemical engineers and project managers) could constrain the pace of synfuels development. On the other hand, problems stemming from shortages of skilled craftsmen, construction materials, or specialized equipment probably can be averted because of the long leadtime before they are needed in large numbers. However, some metals needed for certain steel alloys are obtained almost exclusively from foreign sources.

Many variables affect the rate of development, and predictions are extremely speculative. It is OTA's judgment that **under favorable circumstances, fossil fuel-based production of synthetic transportation fuels could be** 0.3 **to** 0.7 **MMB/D by 1990, growing to 1 to 5 MMB/D by 2000,** depending on the success of the first round of synfuels plants and the fraction of those plants that produce **transportation fuels** as opposed to fuel gases or fuel oils. Achievement of 0.3 MMB/D by 1990 assumes that a sizable commercialization program, such as that being pursued by the Synthetic Fuels Corp., is carried out, but that technical problems limit total production; 0.7 MMB/D would require an increased number of plant commitments within the next year or so, a virtually complete emphasis on liquid transportation fuels, and a high level of technical success with the first plants.

It **must be stressed that even the "low"** 0.3 MMB/D **production level maybe considered as optimistic** in light of current expectations of at least short-term stability in oil prices, as well as remaining technical and environmental uncertainties. In addition, the dismantling of DOE's demonstration program may increase the perceived and actual technological risks of synfuels

development. Thus, **the goals of the National Synfuels Production Program, created by Congress in 1980—0.5 MMB/D by 1987 and 2 MMB/D by 1992—appear unattainable without a crash program that would involve extraordinary technical and economic risks and extensive Government intervention.**

costs

The costs of synfuels are uncertain. First, the factors that limit rapid deployment of the industry also affect its costs. Technical uncertainties complicate cost evaluation, and long shakedown times and potential construction delays would be very expensive at prevailing interest rates. Second, synfuels' relatively high capital costs mean that their total costs are especially sensitive to the type of financing used, the level of interest rates, and the rate of return required by the investors. The present high level of uncertainty in capital markets therefore translates into a high level of cost uncertainty. In addition, the long construction times associated with synfuels plants make them vulnerable to hyperinflation. *

OTA has projected synthetic fuel costs based on the best available cost estimates in the public literature and OTA's previous oil shale study.[1] These sources indicate that, if the potential for cost overruns is not considered, the capital investment (in 1980 dollars) for a 50,000 bbl/d (rated capacity) synthetic fuels plant will range from $2.1 billion to $3.3 billion, or $47,000 to $73,000/bbl/d of production (assuming the plant produces at 90 percent of rated daily capacity). Total plant investments for a 5 MMB/D synfuels industry would thus be about $250 billion to $400 billion. Based on past experience, however, there is a very high probability that final costs will be greater than these ranges.

For example, an extrapolation from recent cost overruns in the chemical industry widens the single plant (50,000 bbl/d) range to $2.3 billion to

$4.7 billion (excluding direct liquefaction, for which cost estimates are less reliable), or about $50,000 to $110,000/bbl/d. Other related investments (e.g., coal mining) raise the total to $50,000 to $125,000/bbl/d. The investment costs per barrel per day of production may be further inflated by performance levels below the 90-percent design factor, although presumably this will be a problem only with first generation plants.

The actual selling price of synthetic fuels will be determined in the marketplace by the prices of competing fuels regardless of the costs of production. Using the projected synfuels production costs, however, OTA calculated the price that service stations **would have to charge** in order for the synfuels producer to attain a required return on investment. Table 4 displays these "prices" for a few alternative combinations of financing and real* return on investment.

Based on these estimates, it is clear that **companies that must bear the full investment burden of a new synfuels plant are unlikely to invest in synthetic fuels production unless: 1) they view this investment as one of low risk and worthy of a low expected return on investment, 2) they expect fuel prices to rise very sharply in the future, or 3) they are willing to take a loss or low return to secure an early market share. The first alternative is not credible for the first generation of commercial plants.**

With the large (75 percent of project costs) loan guarantees that are possible under the En-

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*The real rate of return is the nominal rate of return minus the inflation rate.

Table 4.—Price of Synthetic Fuels Required To Sustain Production Costs[a] (1980 $/gal of gasoline equivalent)

Price (pretax)	Financing	Real return equity investment
$0.80-$1 .10...	100% equity	50/0
$1.30-$1.60, . .	1000/0 equity	10%0
$1.70-$2 .40...	100% equity	15 "/0
$0.80-$ 1.10...	25°/0 equity, 75°/0 debt	10 "/0

[a] Assumptions: no cost overruns, $1 .20/million Btu coal, 5 percent real interest rate on debt financing, $.20/gallon distribution cost including retailer profit. For more details, see ch. 8, table

SOURCE: Office of Technology Assessment.

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*Hyperinflation **in construction costs of major capital projects is a relatively recent phenomenon, however, and some industry analysts consider it a temporary aberration.**

[1] U.S. Congress, Office of Technology Assessment, *An Assessment of Oil Shale Technologies,* **OTA-M-1 18 (Washington, D. C.: U.S. Government Printing Office, June 1980).**

ergy Security Act, * **however, investments in synthetic fuels appear to be attractive even at 1981 fuel prices, but only if current capital cost estimates for synfuels plants are correct and there are no cost overruns. Most industry experts, however, consider the chances of substantial cost overruns to be high.** A cost overrun in plant investment of so percent would increase the necessary price of synfuels by 20 to 30 percent, or else reduce the return on investment.

OTA's cost analysis implies that **significant levels of investment in synfuels production are unlikely at this time without the kinds of financial incentives offered by SFC.** Of course, a further— and currently unexpected—rapid escalation in oil prices could change this conclusion.

Uncertainties associated with the cost estimates are too large to allow in-depth comparison of the costs of the various synfuels. Also, in OTA's opinion, significant reduction of these uncertainties cannot be achieved by further study but will require actual plant construction. **There are indications, however, that shale oil and methanol from coal could be the least expensive options for producing transportation fuels.** Shale oil plants are less complex technically than other synfuels processes and shale oil is relatively easy to refine, thereby suggesting a lower cost. Methanol's high octane and burning characteristics make it more efficient than gasoline in specially designed engines. But materials-handling problems for oil shale, engine technology developments that could offset methanol's efficiency advantage, and unforeseen requirements for process changes could negate these apparent advantages.

Economic Impacts

Development of a fossil fuel-based synthetic fuels industry could create a major new economic activity in the United States, particularly in areas with large reserves of coal or oil shale. There are potential drawbacks, though. For example, be-

cause of synfuel plants' long lifetimes and construction leadtimes, a liquid fuel supply industry based largely on synfuels would be less able than a natural petroleum-based industry to respond quickly to changing market conditions. Rapid synfuels deployment would create a risk that unforeseen market changes could leave the United States with an outdated, idle, capital-intensive industry.

Development of the industry will have other important consequences. For instance, because of the large capital, technical and marketing requirements, and the high risks, small companies are unlikely to enter the market except as parts of consortia. This contrasts sharply with the large number of small-scale producers currently involved in oil and gas development, although ownership concentration in the oil and gas industry will grow in any case as the more easily recovered resources are depleted.

Rapid deployment of a synfuels industry could lead to temporary shortages of equipment, materials, and personnel, which in turn can lead to construction bottlenecks and local inflation. However, long-term inflationary effects are not expected to be large because, in general, the leadtime is sufficient to expand production capacity and labor supply. An important exception may be the supply of experienced chemical engineers and project managers. If shortages of these personnel develop, poor project management or improper plant design could lengthen construction schedules, delay plant startup, and increase costs for chemical plants and oil refineries as well as synfuels plants.

The financial requirements for rapid growth are very large. For example, the rate of investment required to achieve 5 MMB/D of synfuels by 2000 is likely to be greater than $30 billion per year* after the first few years, about as much capital as was spent for all U.S. oil and gas exploration and development in 1979. Making this large a commitment to synfuels would likely divert some investment capital away from conventional oil and gas exploration and development; and this

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*The loan guarantees not only allow synfuels developers to borrow money at somewhat lower interest rates than without them, but the 75 percent debt level is considerably higher than the industry average of about 30 percent. Also, in some cases, the loan guarantee may be necessary to secure any debt capital at all.

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*OTA's analysis of reducing stationary uses of fuel oil was done primarily to provide a reference point and was less extensive than its analysis of synfuels and increased automotive fuel efficiency.

could reduce conventional domestic oil production below the **7** MMB/D assumed for **2000.**

Social Impacts

The principal social consequences of developing a synthetic fuels industry stem from shifting large numbers of workers and their families in and out of local areas as development proceeds. These population shifts disproportionately affect small, rural communities such as those that predominate in the oil shale and some of the coal areas. High population growth rates can lead to disruptions and breakdowns in social institutions; systems for planning, managing, and financing public services; local business activities; and labor, capital, and housing markets. Whether the growth rates can be accommodated depends on both **community** factors (e.g., size, location, tax base, management skills, and availability of developable land), and **technology-related** factors (e.g., the type of synfuels facilities, the timing of development, and labor requirements).

On the other hand, communities should realize social benefits from synfuels development, e.g., increased wages and profits and an expanding tax base. A significant portion of these benefits may not be realized, however, until after the plant is built. In the meantime, the community must make significant expenditures and the overall impact depends substantially on the existence of effective mechanisms to provide the "front end" resources needed to cope with rapid growth.

Environment, Health, and Safety

The production of large quantities (2 MMB/D or more) of liquid synthetic fuels carries a significant risk of adverse environmental and occupational health effects, some of which are quite dependent on the effectiveness of as yet unproven control measures.

The industry will cause many of the same kinds of mining, air quality, solid waste disposal, water use, and population effects as are now associated with coal-fired electric power generation and other forms of conventional coal combustion. Table 5 shows the amount of new coal-fired power generation that would produce the same ef-

fects as a 50,000-bbl/d coal-based synthetic fuels plant, and also directly compares the effects of this plant with a 3,000-MWe coal-fired powerplant. In general, **the emissions of combustion-related pollutants, especially the acid rain precursors sulfur dioxide (SO_2) and NO_x, and the water use of the synfuels plant are significantly lower than for a powerplant processing the same amount of coal.**

To place these effects into perspective, actual coal-fired generating capacity in the United States is about 220,000 megawatts (MW), and about 200,000 MW are expected to be added by 1995. In comparison, SO_2 and NO_x emissions from a 2 MMB/D coal-based synfuels industry would be equivalent to emissions from less than 25,000 MW of power generation, and water use would be equivalent to that of 30,000 MW or less if conservation practices were followed.

On the other hand, **a 2-MMB/D industry (equivalent in coal consumption to 110,000 to 160,000 MW of coal-fired electric generating capacity) would mine hundreds of millions of tons of coal each year, with attendant impacts on acid drainage, reclamation, subsidence and occupational health and safety, and would have substantial population-related impacts such as severe recreational and hunting pressures on fragile Western ecosystems.**

Oil shale development using aboveground retorts has the added problem of disposing of large quantities of spent shale. Although successful short-term stabilization of shale piles has been achieved on a small scale, uncertainty remains about the long-term effects of full-scale development. **The major concern about shale disposal as well as in-situ shale processing is the potential for contamination of ground waters.**

Despite the relatively moderate level of emissions per unit of production, an intense concentration of synfuels development within relatively small areas may yield air quality problems and violations of existing air quality regulations. Such concentration is more likely with oil shale, because of the concentrated resource base. As a result, air quality restrictions may limit oil shale development to under 1 MMB/D unless there are changes in the restrictions or improvements in

Table 5.—Two Comparisons of the Environmental Impacts of Coal-Based Synfuels Production and Coal-Fired Electric Generation[a]

Type of impact	A. Coal-fired generating capacity that would produce the same impact as a 50,000 bbl/d coal-based synfuels plant (MW(e))	B. Side-by-side comparison of environmental impact parameters		Units
		3,000 MW(e) generator	50,000 bbl/d synfuels	
Annual coal use	2,500 -3,600[b]	6.4-15.0	5.3-17.9	million tons/yr
Annual solid waste	(2,500-3,600)±[c]	0.9-2.0+	0.6-1 .8+	million tons/yr
Annual water use:				acre-ft/yr
Current industry estimate. . . .	640-1,300	25,000	5,400-10,800	
Conservation case	400-700		3,400-5,900	
Annual emissions:				tons/yr
Particulate.	120-2,800	2,700	100-2,500	
Sulfur oxides	90-500	27,000-108,000	1,600-9,900	
Nitrogen oxides	60-300	63,000	1,600-7,800	
Hourly emissions:				lb/hr
Particulate.	90-2,200	880	30-800	
Sulfur oxides	70-40	8,800-35,200	500-3,200	
Nitrogen oxides	60-300	20,500	500-2,500	
Peak labor	4,100-8,000	2,550	3,500-6,800	persons
Operating labor	2,500	440	360	persons

a In example A, the powerplant uses the same coal as the synfuels plant, new source performance standards (NSPS) apply, sulfur oxide emissions assumed to be 0.6 lb/10⁶ Btu. In B, NSPS aiso apply but sulfur oxide emissions can range from 0.3-1.2 lb/10⁶ Btu. In both cases, the synfuels piant parameters represent a range of technologies, with a capacity factor of 90 percent and an efficiency range of 45 to 65 percent; the powerplant is a baseload plant, with a capacity factor of 70 percent, efficiency of 35 percent. The major data source for this table was M. A. Chartock, et al., *Environmental Issues of Synthetic Transportation Fuels From Coal: Background Report.* University of Oklahoma Science and Public Policy Program, contractor report to OTA, July 1961.
b In other words, the amount of coal–and thus, the amount of mining–needed to fuel a 50,000 bbl/d synfuels plant is the same as that required for a 2,500-3,600 MW(e) powerplant.
c A synfuels plant will have about as much ash to dispose of as a coal-fired powerplant using the same amount of coal. It may have less scrubber sludge, but it may have to dispose of spent catalyst material that has no analog in the power plant thus the ±.

SOURCE: Office of Technology Assessment.

control technology. In most cases, however, the restrictions do not involve possible violations of the health standards, but rather visibility or other standards.

Aside from these effects, **synfuels development creates a potential for occupational, ecological, and public health damage from the escape of toxic substances formed during the conversion processes.** These include cancer-causing organic compounds, chemically reduced sulfur and nitrogen compounds, and inorganic trace elements. The occupational risks, generally acknowledged as the most serious, are mainly associated with "fugitive" emissions and leaks from valves, gaskets, etc., and with the handling of fuels and plant cleaning. The major ecological and public health risks are associated with contamination of surface and ground waters—from inadequate treatment of wastewaters, leakage from holding ponds or solid-waste landfills, and disruption of aquifers by mining operations—as well as with spills and exposure to contaminated fuels. Fugitive emissions and leaks from the plants also pose some risk to

public health, but at a far lower level than to the plant workers; a potentially important impact of the public's exposure to these substances, however, is likely to be discomfort from their odor.

The risks associated with these toxic substances, although possibly the most serious of synfuels' potential environmental risks, are **not** quantifiable at this time. However, it does appear possible to differentiate, at least tentatively, among some of the basic process groupings in terms of their comparative risk. Direct processes (e.g., Exxon Donor-Solvent, SRC II) appear to present the greatest risk because of their comparatively large number of potential sites for fugitive emissions, high production of toxic hydrocarbons, and abrasive process streams. Indirect processes using low-temperature gasifiers (such as Lurgi) maybe intermediate in risk because they produce relatively large quantities of toxic hydrocarbons. Indirect processes using high-temperature gasifiers (e.g., Koppers-Totzek, Shell, Texaco) appear to be the cleanest group of coal-based processes. Finally, if the risks from spent shale are excluded,

the risks from toxics yielded by oil shale processes probably are no worse than those of indirect, high-temperature coal processes.

There is little doubt that it is **technically** feasible to moderate a synfuels industry's adverse impacts to the satisfaction of most parties-of-interest. in OTA'S judgment, however, **despite substantial industry efforts to minimize adverse impacts, the environmental risks associated with toxic substances generated by synthetic fuels production are significant and warrant careful Government attention.**

Current development plans and existing legislation call for strong measures to reduce many of the potential adverse environmental impacts from synfuels plants through intensive application of emission controls, water treatment devices, protective clothing for workers, monitoring for fugitive emissions, and other measures. Virtually all of these measures have been adapted from controls used with some success in the petroleum refining, petrochemical, coal-tar processing, and electric power-generation industries. Synfuels industry spokesmen are confident that the planned controls will adequately protect worker and public health and safety as well as the environment.

Spokesmen for labor and environmental organizations are far less confident, however, and there remain important areas of doubt concerning the adequacy of environmental management. The full range of synfuels impacts–especially those associated with the toxic substances created or released in the conversion processes—may not be effectively regulated. Existing regulations do not cover many of these toxic substances, and extending regulatory controls to provide full coverage will be difficult. Critical stumbling blocks are the large number of separate compounds that must be controlled, and the recent reductions in the budgets of Federal environmental agencies and reemphasis of their synfuels research programs. Detecting synfuels environmental damages and tracing them to their sources—a key requirement in establishing and enforcing control standards—may be difficult because many of the damages will occur slowly and the relationship between cause and effect is complex.

Another important concern is the possibility that the industry's environmental control efforts may not be sufficient to avoid environmental surprises. Federal Government personnel are concerned that many developers are focusing their control programs on meeting immediate regulatory requirements and are reluctant to commit resources to studying and controlling currently unregulated pollutants. Also, despite pollution control engineers' optimism that all synfuels waste streams are amenable to adequate cleanup, there are still doubts about the reliability of proposed control systems. These doubts are aggravated by differences in process conditions and waste streams between synfuels plants and the refineries, coke ovens, and other facilities from which the proposed controls have been borrowed, and also by a lack of testing experience with integrated control systems.

Water Availability for Synfuels Development

When aggregated nationally, water requirements for synfuels development are small (producing 2 MMB/D oil equivalent requires only about 0.2 percent of estimated total current national freshwater consumption). Nevertheless, these requirements may have significant impacts on competing water uses. In each of the river basins where major coal and oil shale resources are located, there are hydrologic as well as political, institutional, and legal constraints and uncertainties involving water use (e.g., conflicts over the use of Federal storage, Federal reserved water rights including Indian water rights claims, interstate and international compacts and treaties, State water laws). In addition, existing water resource studies vary in the extent they consider water availability factors and cumulative impacts.

Given the uncertainties that surround the question of water availability generally, only limited conclusions about possible constraints on future synfuels development can be drawn. This is especially true in areas where institutional rather than market mechanisms play a dominant role in obtaining and transferring water rights. Where efficient markets do exist, however, water is not likely to constrain synfuels development because de-

velopers can afford to pay a relatively high price for water rights.

In the major Eastern river basins where coal reserves are located (the Ohio, Tennessee, and Upper Mississippi River Basins), **water should be adequate on the main rivers and large tributaries,** without new storage, to support planned synfuels development. In the absence of appropriate water planning and management, however, **localized water shortages could arise during abnormally dry periods or from development on smaller tributaries.**

In the West, competition for water already exists and is expected to intensify with or without synfuels development. In the coal-rich **Upper Missouri River Basin,** the magnitude of the legal and political uncertainties, together with the need for major new water storage projects to average-out seasonal and yearly streamflow variations, **make it impossible to reach an unqualified conclusion as to the availability of water for synfuels development.**

In the **Upper Colorado River Basin,** where both oil shale and coal are located, **water could be made available to support initial synfuels development—as much as a few hundred thousand barrels per day of synfuels production by** 1990—but political and legal uncertainties in the basin make it difficult to determine which sources would be used and the actual amount of water that would be made available. Water availability after 1990 will depend both on how these uncertainties are resolved and on the expected continuing growth in other uses of water.

Reducing Stationary Uses of Oil

Stationary uses of oil include space heating and cooling of buildings, electricity generation, production of industrial process heat, and use as a chemical feedstock. These currently account for nearly half of the oil used in the United States— about 8.1 MMB/D out of a total of 16.8 MMB/D in 1980. Of this, about 4.4 MMB/D are fuel oils— middle distillates and residual oil. The remainder include liquefied petroleum gas, asphalt, petroleum coke, refinery-still gas, and petrochemical feedstocks.

Only reductions in the fuel oil portion of the stationary oil uses are likely to lead to actual reductions in imports. The other oil products are difficult to upgrade to premium fuels or use directly in transportation applications and, consequently, a reduction in their use probably would have little effect on the supply of transportation fuels. On the other hand, the crude oil fractions normally used to produce residual and distillate fuel oils can instead be converted profitably into transportation fuels by refining.

Reductions in fuel oil use can be accomplished by fuel switching and conservation. In the buildings sector, natural gas and electricity can replace distillate oil, and insulation, furnace improvements, and other conservation measures can reduce fuel use in general. For utilities, conservation in all sectors that use electricity can reduce generation requirements, coal and nuclear can replace residual oil for baseload operation, and natural gas can replace distillate oil in peaking turbines. industrial oil use can be reduced by increases in process efficiency and fuel switching to coal, * natural gas, and electricity.

Projection of Oil Savings

The Energy Information Administration projects that the fuel oil consumed in stationary uses will decline from today's 4.4 MM B/D to 2.6 MM B/D in 1990, assuming a 1990 price of $41/bbl of oil (1979 dollars). This 2.6 MMB/D is the target for further stationary use reduction OTA has assumed for this study.**

OTA has evaluated two approaches to eliminating the remaining 2.6 MM B/D stationary fuel oil use by 2000. One approach involves total reliance on fuel switching. Table 6 shows the energy needed to displace the 2.6 MMB/D, substituting coal for residual oil and natural gas and/or electricity for distillate oil.

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*The Energy Information Administration has predicted that, by 1990, most of the industrial processes that can use coal (primarily large boilers) will have been converted. Therefore, OTA'S calculations of post-1990 fuel-switching opportunities do not include coal switching in the industrial sector.

* "If oil prices continue to decline in real dollars or stabilize at current levels, 1990 stationary oil use is likely to be greater than projected.

**Table 6.—Summary of Annual Energy Requirement To Displace
2.55 MMB/D of Stationary Fuel Oil Use**

Sector	Oil (M MB/D)	replaced by Coal (10⁶ tons)	plus (tfc)	or Electricity (10' kWh)
Buildings 1.2		—	2.4	425
Industry 0.3		—	0.6	120
Utilities. . . . . 0.9 (resid.)		100	—	—
0.15 (dist.) . .		—	0.3	—
Total 2.55		100	3.3	545

SOURCE: Office of Technology Assessment.

The **technical** capability to accomplish this level of switching depends on two factors. First, if natural gas is to play a major fuel-switching role, production of unconventional gas sources* will be needed. A key to this is the future price of gas. Second, production of additional electricity and switching to coal in utility boilers depends primarily on the utility industry's ability to solve its current financial problems and gain access to capital. Either of these potential constraints could severely restrict fuel switching.

A second approach combines fuel switching with measures to conserve oil, natural gas, and electricity. If conservation measures can save enough natural gas and electricity to replace the (reduced) oil requirement, additional gas and electricity production may not be needed. An analysis by the Solar Energy Research Institute (SERI) indicates that conservation measures in the buildings sector alone could save about 1.5 times as much natural gas and electricity as would be required to replace all remaining stationary uses of distillate and residual fuel oil by 2000.** This combined approach has fewer technical constraints than the "fuel switching only" approach. In OTA'S judgment, **a significant fraction of the 2.6 MMB/D of stationary fuel oil use expected in 1990 can be eliminated by 2000 by conservation and fuel switching taken together.**

Despite the lack of absolute constraints, however, it is unrealistic to expect total elimination or near-elimination of stationary fuel oil uses by 2000. First, average capital costs are high enough to discourage those investors who apply a high

discount rate to their investments. Second, the site-specific variability and the large number of different types of measures imply that some of the individual measures will be far more expensive than the average. * Third, the record of oil-to-coal switching in industry during the past decade has not been a good one despite apparently favorable economic incentives. Finally, the continued reduction in supplies of high-quality "light" crude may lead to excess supplies of residual oil in the 1990's, driving down its price and making conversion from residual oil to coal uneconomical in some cases. To a certain extent the latter effect will be offset by the economic attractiveness of retrofitting oil refineries to produce less low-priced residual oil and more gasoline, jet fuel, and diesel fuel.

costs

The investment costs for the two strategies for reducing stationary oil uses are similar. OTA has calculated the investment cost of the strategy that relies mainly on fuel switching to be roughly $230 billion, or an average of $90,000/bbl/d of oil saved. Using SERI'S cost analysis, the strategy that combines strong conservation measures and replacement of the remaining oil use with electricity and natural gas was calculated to cost roughly $225 billion, or $88,000/bbl/d of oil saved. The difference between the estimated costs for the two strategies is too small to be meaningful.

Both the investment costs and the operating costs paid by individual investors will vary over an extremely wide range, This is particularly true because the "strategies" are actually a combina-

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*These sources include tight sands formations, geopressurized methane, coal seam methane, and Devonian shale formations.
* *Assuming that all such stationary uses are reduced by conservation as well.

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*By the same reasoning, many will be less expensive than the average.

tion of several markedly different kinds of investments. For example, conversion of oil-burning utility boilers to coal has an average investment cost of $74,000/bbl/d of oil replaced, whereas conversion of distillate-using facilities to natural **gas** averages $114,()()()/bbl/d (including the cost of obtaining the new gas). Also, the costs of each type of investment will vary from site to site.

Electric Vehicles*

Automobiles can be powered by rechargeable batteries that drive an electric motor; indeed, some of the first automobiles used battery-electric powertrains. Present concepts of electric passenger vehicles generally envision small vehicles for commuting or other limited mileage uses, with recharging at night when electricity demand is low.

Projections of Use

OTA does not expect electric cars to play a significant role in passenger transportation in this century. Battery-electric cars are likely to be very expensive, costing about $3,000 more in 1990 than comparable gasoline-fueled autos. And this consumer investment may not yield any savings in fuel costs. If batteries must be replaced every 10,000 miles, as required with current technology, total electricity plus battery costs will actually be considerably higher than gasoline costs for a comparable conventional auto, even at $2.00/gal gasoline prices (1980 dollars).

Another reason that OTA is not optimistic is that progress in electric vehicles remains severely limited by battery performance. Currently available batteries and components require 6 to 12 hours for recharging and limit electric vehicles to a range of less than 100 miles between charges. Acceleration is limited to about O to 30 mph in 10 seconds, which is lower than the poorest performing (O to **40** mph in 10 seconds) gasoline and diesel fuel cars and may not be adequate for many traffic conditions. Although predictions of significant reductions in battery size and weight

continue, in OTA'S judgment current understanding of battery performance does not permit accurate predictions of future improvements.

Even if sufficient progress is made in battery development to encourage extensive usage of electric cars, **electrification of automobile travel does not offer the same potential for oil savings as the other options.** Under the best of circumstances, **most electric passenger vehicles are likely to be small, limited-performance vehicles that will substitute for small, fuel-efficient conventional autos.** Consequently, **a 20-percent electrification of the auto fleet is not likely to save more than about** 0.2 MMB/D. *

Environment, Health, and Safety

If technical developments, severe liquid fuel shortages, and/or Government promotion were to result in significant sales of electric vehicles, the major environmental impacts probably would be the air quality and other effects associated with reducing auto emissions and increasing electricity generation. **The overall effects of widespread use of electric vehicles on urban air quality should be strongly positive, because the electric cars would tend to be clustered in urban areas, many of which have chronic automobile-related air pollution problems that would be eased by the displacement of conventional automobiles.** There would be, however, a small net increase in regional and national emissions of SO_2, because conventional autos have few or no SO_2 emissions to offset the SO_2 emissions from fossil-fueled electric power generation for battery recharging. Additionally, when coal is the fuel source for recharge electricity, the amount of coal mined per unit of oil replaced is comparable to that for synfuels production,** with similar coal mining impacts. Material requirements for batteries could add substantially to the demands for certain minerals, e.g., lead, graphite, and lithium.

Electric passenger vehicles are likely to be small and thus should share safety problems

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[2]See, Synthetic Fuels for Transportation: The Future Potential of Electric and Hybrid Vehicles–Background Paper No. 1, OTA-BP-E-13 (Washington, D. C.: U.S. Congress Office Of Technology Assessment, April 1982).

*Assuming no oil is used for electricity production and the average gasoline- or diesel-powered vehicle replaced gets 60 mpg.

* *That is, 1 ton of coal yields the same oil savings in either technology.

with small conventional automobiles. Additional safety and health problems may be caused by the batteries, which contain toxic chemicals that may pose occupational problems in manufacturing and recycling and may be hazardous in an accident-caused spill; this latter problem is balanced somewhat by eliminating the fuel tank with its highly flammable contents. Finally, extensive outdoor charging of vehicle batteries may pose public safety problems from the electrocution hazard.

Chapter 2
Introduction

Contents

FIGURE

Petroleum has been at the heart of the Nation's efforts to secure its energy future since the 1973-74 oil embargo. Petroleum products currently supply about 40 percent of total U.S. energy needs, and imports account for approximately **30** percent of total petroleum demand. The increases in the price of imported crude that have occurred since 1972—a barrel of imported crude that was selling for $4.80 in 1972 was selling for $31.40 (both expressed in constant 1980 dollars) as of February 1982–have severely strained the national economy by contributing to domestic inflation and trade deficits and by altering demand patterns.

Instead of increasing gradually, petroleum prices have gone up in two large, rapid jumps. These price "shocks" have exacerbated strains on the economy by preventing an orderly adjustment to higher fuel prices. Future price behavior is also very uncertain and complicates economic planning. Subsequent to decontrol of domestic crude oil prices, a continued increase in the price of oil was generally expected. The sharp drop in demand, coupled with reemergence of Iran on the world oil market, however, has created downward pressure on oil prices. A substantial drop in the real price of oil over the next few years is quite possible.
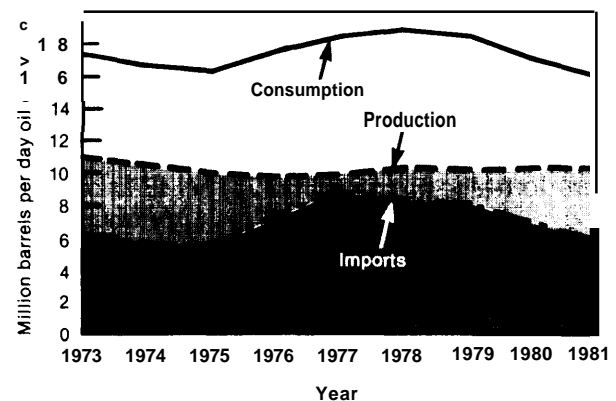
This oil glut will not last indefinitely, however. Indeed, importing nations will eventually again face increasing competition for oil arising from a combination of dwindling world supplies* and increases in demand from both producing and developing nations. This, in turn, will force oil price increases with the possibility that they may again come in the form of price shocks rather than an orderly rise. Thus, the U.S. petroleum problem is not simply that we import oil–indeed, in a stable, economically rational world import-

*OTA estimates that non-Communist world oil production could range from 45 to 60 MMB/D in 1990 and 40 to 60 MMB/D in 2000, compared to 46 MM B/D in 1980. While an increase in world production is possible, it is more likely that production will remain fairly stable or slightly decline. See *World* Petroleum *Availability 19802000-A Technical Memorandum* (Washington, D. C.: U.S. Congress, Office of Technology Assessment, October 1980), OTA-TM-E-5.

ing could be economically efficient-but that the supply and price is subject to so much uncertainty and dramatic change.

For 1981, the Nation's imports of crude oil and petroleum products averaged about 5.4 million barrels per day (MMB/D), accounting for about 34 percent of total petroleum demand. These figures compare with 7.5 MMB/D of imports, about 41 percent of total petroleum demand, for 1980. In fact, imports and demand have been on a steady downward trend since their peak in 1978, when imports of 8.2 MMB/D represented 44 percent of total demand (see fig. 3). The principal cause of this downward trend in imports and their share of total petroleum demand was the nearly 120-percent increase in the real price of crude oil since 1978. If the trend were to continue, oil imports could be eliminated by the end of the century.

There is considerable disagreement, however, on whether this trend can be maintained. The current downward trend of prices as a result of a soft market has already been noted. The principal focus of disagreement, however, is the adequacy of the Nation's future domestic supply. The current domestic production of crude oil and natural gas liquids is 10.2 MMB/D. Production of these two liquids has been declining steadily since

Figure 3.—U.S. Petroleum Consumption, Domestic Production, and Imports

SOURCE: Energy Information Administration, U.S. Department of Energy.
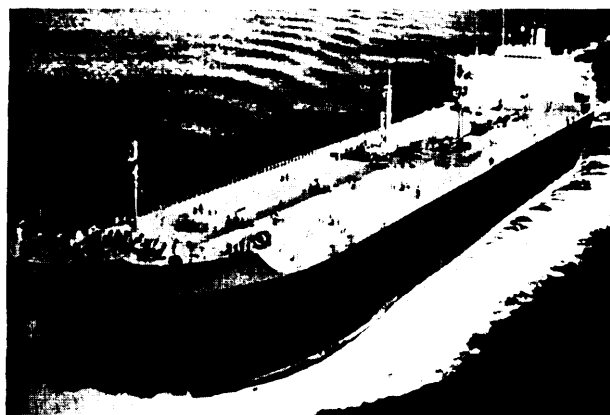
29

Photo credit: U.S. Department of Energy

**Oil tankers deliver most of the crude oil imported
to the United States**

the peak year of 1970, when it reached 11.3 MMB/D, although the decline has slowed noticeably the last 3 years (see fig. 3). This, coupled with the remarkable upsurge in drilling activity since 1979, has caused some forecasters to predict an increase in production before the end of the century. In its most recent forecast, under a high world oil price scenario, for example, the Energy Information Administration of the Department of Energy forecasts a production rate of 11.2 MMB/D of crude oil and natural gas liquids by 1995.1

Despite this increase in drilling and exploration activity, as figure 3 shows, the effect of higher oil prices to this point has been almost exclusively in reducing demand, not increasing supply. In addition, the Office of Technology Assessment in a study, *World Petroleum Availability: 79802000,* did not find any evidence that a significant upturn in domestic production would occur.[2] In fact, OTA estimated a production rate of **5** to *8* MMB/D by 1990 and 4 to 7 MMB/D by 2000. Exxon's most recent energy outlook forecast domestic production of 7.1 MMB/D by 1990 and 7.8 MMB/D by 2000.[3] Thus, production rate

estimates for the middle 1990's differ by as much as 7 MMB/D, an amount greater than current U.S. imports.

In OTA'S judgment, the lower rates estimated in its study are still valid and it would be imprudent to assume otherwise in planning for the 1990's. The principal justification for these lower rate estimates is not so much an actual decline in total oil reserves as the increasing difficulty in extracting the oil that is found. The rate at which oil can be produced is declining because oil is no longer being found in the very large oilfields necessary to sustain or increase total production.

If domestic production does decline to 5 or 8 MMB/D by the mid-1990's, demand will have to decrease even faster than it has during the last few years just to keep imports at their current level. It is possible to greatly reduce petroleum product demand by both fuel switching and increased efficiency of use. This will require a substantial investment, however, and it is not clear yet whether it will be made. The current demand response is a combination of shortrun elasticity to the most recent price rise and the longer run elasticity—involving turnover of capital stock—to the 1973-74 price rise. Current forecasts of energy demand all show a continued, but slower, decline in petroleum demand for the rest of the 1980's but a steadying during the 1990's. In all cases, substantial imports will be necessary in the 1990's if the decline in domestic production assumed above takes place.

Faced with similar prospects after the 1973-74 oil embargo, Congress enacted a wide range of legislation to encourage a reduction of the Nation's dependence on oil imports. First, legislation was enacted to reduce petroleum demand. Foremost among these initiatives was the establishment in the Energy Policy and Conservation Act of the 1985 Corporate Average Fuel Efficiency (CAFE) standards for automobiles. More than half of total U.S. petroleum demand is in the transportation sector, which, in turn, uses about half of its petroleum in passenger vehicles. Other legislation to reduce petroleum demand included: 1) the Powerplant and Industrial Fuel Use Act, whose provisions require large combustors to convert from oil by 199o; and 2) systems of tax credits and financial programs to encourage

1 Annual Report to Congress, 1 9 8 0 , vol. **3, DOE/EIA-01 73(80)/3, Energy Information Administration, U.S. Department of Energy, Washington, D. C., March 1981, p. 85.**

2 *World Petroleum Availability: 1980-2000-A Technical Memorandum* **(Washington, D. C.: U.S. Congress, Office of Technology Assessment, October 1980), OTA-TM-E-5.**

[3]**Energy Outlook:** 1 9 8 0 - 2 0 0 0 , **Exxon Co., U. S. A., Houston, Tex., December 1980, p. 7.**

capital investments for energy conservation in industry and buildings. Finally, legislation was passed to augment domestic supplies of petroleum substitutes through the production of synthetic fuels. The Energy Security Act of 1980 established the Synthetic Fuel Corp., with synfuel production goals of **0.5** MMB/D in 1987 and 2.0 MMB/D by 1992.

The efficacy of this approach is now being re-evaluated, not only because of the time limitations of the legislation, but also in light of the price increases of 1979, which have caused the Nation to reduce imports more quickly than originally anticipated. The debate centers on whether the Government should continue its approach of the 1975-80 period—and if so which path or paths would be more effective-or whether the Nation can depend primarily on the current high oil cost —not entirely anticipated when the original legislation was passed–to reach an acceptably low level of oil imports. Complicating current debate is uncertainty about where oil prices will go in the immediate future. A steady decline in real prices over the next few years could substantially reduce market pressure toward increased conservation and development of alternative fuels, with the result that the Nation will be that much more economically vulnerable should there be dramatic upsurges in prices later in the decade or throughout the 1990's. Further, no matter which approach is preferable, general concern exists about the side effects of the Nation's movement to free itself from import dependence.

Of particular interest in the ongoing evaluation of policy are the approaches directed at producing synthetic liquid fuels and at reducing petroleum consumption by automobiles. These are by far the largest programs enacted by Congress, both in terms of their costs and of their effects on the economy.

In 1979, the Senate Committee on Commerce, Science, and Transportation requested OTA to assess and compare these two approaches to reducing oil imports. Because mandated increases in CAFE standards were to end in 1985, the committee was interested in whether further standards would be more or less effective than the synfuels program in reducing oil imports. The large

increase in oil prices since 1979 and the response to this increase have changed the environment in which that request was made. As a result OTA has broadened its study to consider how far and fast automobile efficiency and synthetic fuels production can develop during the next 20 years, and to evaluate the effects on and risks to the industries involved. Such an evaluation is particularly important for the automobile industry because of its current precarious state. No matter what course the Nation chooses—continued regulation or more reliance on market mechanisms —the industry may be in for continued difficulties if the need for large capital investments continues while demand for automobiles remains relatively low.

In addition to assessing the import reducing potential of synfuels and increases in automobile fuel efficiency, this study also examines, although in considerably less detail, the oil savings that could be gained through fuel switching and conservation by stationary oil users. By combining the three approaches, plausible development scenarios for reductions in oil consumption are derived, leading to estimates for oil imports over the next 20 years.

The body of this report starts with an analysis of policy options that: 1) could influence the rate at which oil imports can be reduced or 2) affect the consequences of changes needed to reduce conventional oil consumption. The next chapter presents the major issues and findings of the report, including a discussion of the cost of oil imports, comparisons between increased automobile fuel efficiency and synfuels, and analyses of issues related solely to one or the other of these options.

The remaining chapters of the report contain the background analyses. Separate chapters on increased automobile fuel efficiency, synfuels, and stationary uses of petroleum present the technical and cost analyses for each. The final chapters analyze the economic and social effects and environmental, health, and safety impacts *associ*ated with both increased automobile fuel efficiency and synfuels, as well as the availability of water for synfuels development.

Chapter 3
Policy

Contents

TABLES

INTRODUCTION

Success of any efforts to reduce oil imports will depend on many complex, unpredictable factors, including world oil prices, the success of technological developments, consumer behavior, general economic conditions, and–significantly –Government policies and programs.

Government policy is vitally important, because energy inevitably affects, whether directly or indirectly, all production and consumption decisions in an industrial society. How quickly and to what level the Nation displaces oil imports have direct implications for who benefits from, and who pays the costs of, energy independence. Such distributional questions arise regardless of policy choices. Thus, the policy choices made by Congress transcend a simple choice between intervention and nonintervention.

This chapter describes the policy issues and options for increasing automobile fuel efficiency and accelerating synthetic fuels development. (For a detailed discussion of policy options related to fuel switching and conservation in stationary uses of petroleum, and to biomass, the reader is referred to other OTA publications.1) The chapter addresses the circumstances which might justify direct Government intervention to displace oil imports. The well-established auto industry and the newly developing synfuels industry are then described; and those economywide and sector-specific characteristics which shape, direct, and pace each industry's ability to displace oil imports are identified. A brief, recent history of Government policy towards each industry is also provided. Finally, the major policy options available to Congress are discussed and evaluated based on the characteristics of the industries.

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'Energy From Biological Processes, **OTA-E- 124, July 1980; Residential Energy Conservation, OTA-E-92, July 1979;** Dispersed Electric Energy Generation Systems, **OTA, forthcoming;** Energy Efficiency of Buildings in Cities, **OTA-E-168, March 1982.**

THE NATION'S ABILITY TO DISPLACE OIL IMPORTS

The three principal means for displacing oil imports-increased automobile fuel efficiency, synfuels production, and fuel switching and conservation in stationary uses—can all make important contributions to the Nation's energy future. Legislation has recently been enacted in all three areas to reduce conventional oil use, including the Energy Policy and Conservation Act of 1975, the Energy Security Act of 1980, the Fuel Use Act, and various taxes and credits to encourage capital investment for energy conservation in industries and buildings. z Some progress in displacing imports can be expected as a result of these Government programs working in concert with market forces.

OTA'S technical analysis, presented in this report, concludes that if Congress wishes to eliminate net oil imports, significant accomplishment in all three areas may in fact be necessary to achieve this goal by 2000 if domestic production falls from 10 million to 7 million barrels per day (MMB/D) or less by 2000, as OTA expects.3 In general, if there are no additional policies and programs, if technology developments are only partially successful, and if strong market forces for import displacement do not materialize, the United States can expect to import 4 to 5 MMB/D or more by 2000 (see issue on "How Quickly Can Oil Imports Be Reduced?" in ch. 4).

In the near future, Congress will face a number of decisions about whether to increase efforts to displace oil imports, and if so, at what speed imports should be displaced, Major decisions will

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2For details of recent **legislation, see for** example Congressional **Quarterly, Inc.,** Energy Policy, **2d cd., March 1981.**

3 World Petroleum Availability: 1980-2000—A Technical Memorandum, OTA-TM-E-5 **(Washington, D. C.: U.S. Congress, Office of Technology Assessment, October 1980).**

concern the two major programs enacted by Congress: the setting of fuel efficiency (Corporate Average Fuel Economy (CAFE)) standards beyond the 1985 mandate for new cars sold in the United States, and the provision of large subsidies to promote rapid development of the synfuels industry. Such decisions will shape the future of both the auto and synfuels industries. Whether new policy initiatives are feasible, practical, and appropriate cannot be determined until Congress specifies the desired level and rate of import displacement. is the goal to "eliminate" or to "reduce" imports?* is this oil import displacement goal so vital to national interests that an emergency effort is required, regardless of any accompanying disruptions and dislocations?

Given the uncertainties, risks, and unpredictability associated with both the automobile fuel-efficiency and synfuels options, it is difficult to determine how far and in what direction present policies and market forces will take the Nation. OTA has not attempted to predict the detailed outcomes of alternative policy futures, but rather to demonstrate that the ability to displace oil depends on complex, interrelated factors, and to demonstrate that the Government's policy choices—whether to implement additional policies or to "do nothing" —will make a difference in the ability to achieve oil displacement goals. Policies are also identified that could be effective if future Government action is necessary.**

OTA'S low estimate is that the average fleet fuel efficiency for new cars could reach at least **40** to **SO** miles per gallon (mpg) by the early to mid-1990's and 45 to 60 mpg by 2000,*** based on

relatively pessimistic expectations about how quickly improved automotive technology is deployed and purchased. Fleet fuel consumption for passenger cars would be about 2.1 MMB/D in 2000, for a cumulative savings of over 1 billion barrels of oil between 1985 and 2000 (assuming that the same proportion of large, medium, and small cars are sold in 2000 as are expected to be sold in 1985). The "high estimate" assumes that technology development is both successful and rapidly introduced into volume production. Average mpg ratings would be **55** to 65 mpg by 1995 and 60 to 80 mpg by 2000; and fleet fuel consumption for passenger cars could be as little as 1.3 MMB/D in 2000 for a cumulative savings of over 4 billion barrels (relative to a 30-mpg fleet and assuming a rapid shift to small cars).

However, the actual level of fuel consumption will depend on market demand for fuel-efficient cars and/or additional Government policies designed to facilitate either the manufacture or purchase of these cars. Although the low estimates are believed to be achievable in the absence of additional Government policies, they would be contingent on consumer expectations that the real price of gasoline will continue to increase. The high estimates are unlikely to be achieved in the absence of supporting Government policies unless a strong and continuing consumer demand for fuel efficiency is coupled with favorable technological progress.

OTA'S estimates for a low- and a high-development scenario for synthetic fuels production depend principally on the price of conventional oil and the ease and rate with which synfuels processes are proven. A rapid buildup of the industry could begin as early as the late 1980's or as late as the mid-l990's, resulting in technically plausible production levels of fossil-synthetic transportation fuels of 0,3 to 0.7 MM B/D by 1990, 0.7 to 1.9 MMB/D by 1995, and 1 to 5 MMB/D by 2000. * In the absence of additional Government policies, the lower estimates are probably attainable but are contingent on a Government-supported commercialization program that reduces the high technical and associated financial risks to private investors of first generation plants.

Without a successful commercialization program, even the low estimates are probably unat-

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*"Elimination of oil imports" herein is assumed to mean the reduction of net oil imports to a level of about O to 1 MMB/D by 2000. At this level, the "security premium" for oil—the difference between the market price and full economic cost to the Nation of oil imports-would approach zero. This level of supplies could be procured primarily from the United Kingdom, Canada, and Mexico; and foreign producers generally would be forced to compete for markets. Because of the "security premium, " policy decisions about the value of displacing imports should not be based solely on the international price of oil.

**An examination of Government policy related to the use of petroleum in the stationary sector is beyond the scope of this report. A summary of the major policy options for the stationary sector, however, is found in app. 3A to this chapter.

***Earlier trends showing relatively strong demand for fuel economy have encouraged some domestic manufacturers to predict new-car fuel economy averages of over 30 mpg by 1985 (the 1985 CAFE standard requires a fleet average of 27,5 mpg), while individual vehicles already on the market exceed 45 mpg.

*These estimates exclude contributions from biomass.

tainable. If there is a commercialization program, synfuels production **theoretically** could reach the high estimates without additional Government programs if: 1) early commercial-scale demonstration units are built and work successfully, and 2) synfuels production becomes unambiguously profitable. The maximum displacement of oil imports, however, would occur only if synfuels production concentrates on transportation fuels. it is OTA'S judgment that, even with a commercialization program, the high estimates are likely to be delayed by as much as a decade unless policies tantamount to energy "war mobilization" are enacted.

Fuel switching and conservation of oil in stationary uses will also be extremely important for displacing oil imports and would complement both fuel-efficiency and synfuels efforts. Although much of the potential for displacement could probably be achieved by market forces by 2000 (under the high oil price scenario of the Energy Information Administration (EIA)),[4] additional policies to encourage fuel switching and conservation will likely be required to accelerate the

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[4]**Department of Energy, Energy Information Adminstration,** *Annual Report* **to** *Congress, vol. II 1*, **May 1982.**

changes or completely eliminate stationary fuel oil use. The level of displacement that can be obtained depends not only on future oil prices, but on financing, regulation, and technical factors. Efficiency increases in the various nonautomobile transportation uses could also be significant.

Displacing oil imports is a necessary but not a sufficient condition for achieving national energy security. Such security translates into an essential self-reliance, availability, affordability, and sustainability of energy resources. Alternative energy sources may present their own set of supply and/or distribution problems. Furthermore, the relationship between the level of imports and the level of insecurity is not proportional in an obvious way. Even if the Nation could eliminate all of its oil imports, U.S. energy security could still be seriously affected if interruptions in world oil supplies threatened international commitments with allies, imbalances in the world monetary system, and pressures on foreign exchange markets. Thus, efforts to displace the Nation's most insecure oil resources—its imports-should not divert attention away from ensuring the resilience of the alternatives chosen and thus the stability of both domestic and international energy systems.

RATIONALE FOR A DIRECT FEDERAL ROLE

The basic rationale for direct Federal involvement in a market economy is that—in limited but important areas—market prices and costs used to evaluate returns on private investments do not reflect the full value and cost of the investments to society as a whole. National security and environmental protection are classic examples of values and costs that are not reflected in profit and loss statements. Private calculation of profits also causes market mechanisms to be most responsive to short-term economic forces as opposed to long-term social and economic goals.

The three principal reasons for such market "failures" are that: 1) some of the social benefits are public and not private goods, 2) some of the costs are not paid by the private sector, and 3) costs and benefits are not fully known. All three

situations arise in the context of displacing oil imports in general and of both increasing automobile fuel efficiency and producing synfuels in particular. The inability of the conventional marketplace to ensure the effective and rapid displacement of oil imports has major implications for the Federal role, depending on the goals chosen and the resources made available.

National security is a public good that has traditionally received Government support. National energy security, promoted by the displacement of oil imports, is an important component of overall security. Direct Government involvement would thus be justified if market forces alone were not believed capable of achieving the quantity and rate of oil displacement required by national security goals. The value to the Nation of

accelerating automobile fuel efficiency increases and synfuels production would be in addition to any private returns to investment.

Both increased automotive fuel efficiency and synfuels production give rise to side effects and tradeoffs; those who benefit from the investments are not necessarily the ones who bear the full costs. Side effects can fall on different sectors of the economy, regions, or consumer groups depending on the investments chosen. In the case of increased automobile fuel efficiency, the rationale for Government policy is that the activities stimulated by market forces alone do not provide, for example, adequate safety and employment safeguards. There are other possible tradeoffs, on the one hand, between improving the competitive position of the U.S. auto industry by encouraging investments in increased auto fuel efficiency, and, on the other hand, possible declines in auto-related employment levels (because of increased automation, contraction of the domestic industry), increased consumer costs, and

decreased safety. With respect to synfuels, Government intervention could be similarly warranted if market decisions do not reflect environmental, health, safety, and other social concerns.

Both increased automobile fuel efficiency and synfuels production are characterized by financial risks and uncertainties. If market forces alone determine outputs, investments associated with these alternatives might be delayed or canceled. In such cases, the Government could choose either to assume some of the risk or to help reduce components of uncertainty. The auto industry's uncertainty focuses on unpredictable consumer demand for fuel-efficient cars, the long leadtimes for investments, and, to a lesser degree, on the rate of technological development. Synfuels production is subject to significant technological uncertainties and, in turn, financial risks. Both the auto and synfuels industries are also affected by uncertain and as yet undetermined future Government policies.

DISTINGUISHING FEATURES OF INCREASING AUTOMOBILE FUEL EFFICIENCY AND SYNTHETIC FUELS PRODUCTION

The major forces that will shape, direct, and pace increases in automobile fuel efficiency and synfuels production are summarized in table 7. Identifying these forces may indicate both the potential opportunities for and limitations of Government policies in achieving a desired level and rate of import displacement, and the appropriateness, practicality, and desirability of specific policies or combinations of policies.

Although increased automobile fuel efficiency and synfuels production share several attributes, essential differences between them suggest that there is no single role for Government policies and programs. These two options should be viewed as complementary measures for reducing oil imports. Each option has different implications for the rate of oil import displacement and will give rise to different types of economic and noneconomic impacts on the Nation. In addition, within the uncertainty about investment costs (per barrel per day oil equivalent (B/DOE) pro-

duced or saved), neither increased automobile fuel efficiency nor synfuels production appears to have an overall unambiguous enconomic advantage over the other. For this reason, the non-monetary and often nonquantifiable differences between these options will be the principal means for distinguishing between them for policymaking purposes.

The factors that determine the rate of fuel switching and conservation in stationary applications will share some common elements with automobile fuel efficiency increases and synfuels production. The success of fuel switching will depend critically on the efficiency of stationary energy uses, the technologies for producing natural gas from unconventional sources, the supply and future price of conventional natural gas, and the ability of the utility industry to solve its current financial problems. in the absence of mandated conservation or performance standards, conservation measures will depend primar-

Table 7.—Distinguishing Features of Increasing Automobile Fuel Efficiency and Synfuels Production

Increasing automobile fuel efficiency	Synfuels production
1. Both near- and long-term restructuring of an existing industry	1. Growth and promotion of a new industry
2. Dominated by a few large, mature companies	2. Likely to be dominated by a few large, mature companies
3. Automobiles as consumer durables; differentiable; deferrable	3. Synfuels as uniform, consumable commodities
4. New technology involved, but can proceed incrementally; associated risks are an ongoing feature of industry	4. Large technical risks; possibilities for "white elephants, " major risk occurs with first commercial-scale demonstration plants
5. Industry must produce competitive products each year, including fuel-efficient cars	5. Sponsoring industry is involved in a breadth of activities that provides alternative investment and business opportunities, of which synfuels is one
6. Precariousness of industry's current financial position; need to ease readjustment of an industry in distress	6. Soundness of sponsoring industry's current financial position; need to facilitate growth
7. Large demand uncertainty	7. No unusual demand risk except insofar as synfuels differ from conventional fuels
8. Dispersion of industrial activities, domestically and, increasingly, internationally; some concentration of activities in the North-Central region of the United States	8. Dispersion of activities among coal regions; current oil shale activity concentrated in a small area of the West
9. Capital intensity and associated risks	9. Capital intensity and associated risks
10. Declining profit margins in domestic industry	10. Potential for profit still highly uncertain
11. Significance of international competition (i.e., auto imports); importance of domestic market to financial viability	11. Long-term export potential; importance of international competition (i.e., oil imports) in terms of establishing the marginal price
12. Large amounts of capital continually required for redesign, retooling, etc.; final costs for improved fuel efficiency uncertain; calculation of capital costs for fuel economy dependent on methods for cost allocation	12. Large amounts of capital required primarily in the initial construction phase; final costs for synfuels production uncertain
13. Can make significant contributions to reducing U.S. oil imports; contributions have a long leadtime but can have significance incrementally	13. Can make significant contributions to reducing U.S. oil imports; contributions have a long leadtime and will not be significant until commercialization
14. Caters to a saturated market; focus on product replacement rather than growth markets	14. Caters to a slowly growing or possibly declining market
15. Consumer costs are investment to reduce future fuel purchases	15. No investment needed by consumer; consumer pays incrementally for each increment of consumption
16. Reduces consumption of fuel	16. Substitutes one fuel for another
17. Fuel savings in automobiles limited to about 3.5 MMB/D with about 1.5 MMB/D savings coming from achieving a 30-mpg fleet	17. Fuel-replacement potential ultimately limited by demand for synfuels, environmental impacts of synfuels plants, and coal and oil shale reserves
18. Principal health impact may be increased auto deaths due to smaller cars	18. Environmental and health impacts from: large-scale mining of coal and oil shale; possible escape of toxic substances from synfuels reactors (major risks are direct worker exposures, contamination of ground water); visibility degradation; development pressures on fragile, arid ecosystems

SOURCE: Office of Technology Assessment.

ily on investor behavior. Although there are few technical constraints, there are technical uncertainties about the conservation potential of buildings and the success of particular conservation investments. Both fuel switching and conservation are difficult to put into practice because the measures are varied, site-specific, and in some cases costly.

Factors Affecting the Rate of Automobile Fuel= Efficiency Increases

In order to be internationally competitive, the domestic automobile industry is currently undergoing major structural adjustments. 5 This readjustment is the consequence of two interrelated forces. First, the domestic industry is undergoing a long-term restructuring that is being experienced by auto manufacturers worldwide. Resource pressures and a trend towards small, fuel-efficient, and standardized "world cars" have resulted in a period of corporate consolidation, with firms being more closely tied by joint design and/or production ventures, and a geographic dispersion of product assembly. Secondly, U.S. auto manufacturers are uniquely faced with a series of short-term problems that arise because they have historically served a market that demanded large, relatively fuel-inefficient cars. U.S. manufacturers have been the principal producers (and promoters) of large cars and have historically earned their greatest profit margins on these cars.

The strains placed on the domestic industry, as it redesigns its products and retools its facilities for fuel efficiency in the near and midterm,6 are the forces that could most appropriately be targeted and eased by Government policies. In addition, because of the size and dispersion of the U.S. auto industry throughout the national economy, maintaining the health of the industry and minimizing the side effects on both upstream activities (e.g., dealers, suppliers), and downstream activities (e.g., consumers) are of potentially great Government concern.

Some aspects of the domestic industry's short-term readjustment problems are caused by economywide factors such as rising energy prices, tight credit, and high interest rates. These factors have affected both manufacturers—by making capital scarce and expensive—and consumers, who (with approximately two-thirds of all purchases historically being on credit) are deferring purchases.

The market changes associated with high gasoline prices and the threat of gasoline shortages experienced in the 1970's have shown that consumer demand is the most powerful influence on the rate and manner of fuel-efficiency increases. However, the prices consumers will pay, and the tradeoffs consumers will accept in vehicle attributes—of which fuel efficiency is only one—are highly uncertain and ambiguous. For example, in the mid-1 **970's,** and again in 1980-81, the proportion of relatively small cars purchased to large cars purchased decreased. * Furthermore, consumers did not consistently buy the most fuel-efficient car in a given size class. The ability of the industry to sell cars is made additionally difficult because there has been a steady slowing in the total demand for automobiles due to stagnant per capita disposable income and a general aging of the population, implying that the industry is mainly serving a domestic replacement rather than growth market. And at the same time, imports have captured an increasing share of the domestic market.

The need to make large investments under conditions of uncertain demand for fuel efficiency and slowing overall demand for automobiles, aggravated by economywide stresses, is the most significant contributor to the financially precarious position now facing the domestic auto industry. Losses to U.S. auto manufacturers exceeded $4 billion in 1980. As sales have decreased, profits have declined, and the industry's longstanding ability to reinvest with internally generated funds has decreased. Because the industry is capital-intensive, any underutilization of capacity also implies large costs. Large amounts of outside capital will be required to retool for increasing fuel economy. If companies are forced to cut back on their capital investment programs in the near term (as some are doing), they will not only forestall fuel-efficiency improvements but may also become increasingly vulnerable to foreign competition. [7]

In adjusting to this, U.S. manufacturers face a series of complex decisions. Domestic manufac-

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[5]See also *U. S. Industrial Competitiveness-A Comparison of Steel, Electronics, and Automobiles,* **OTA-ISC-135 (Washington, D. C.: U.S. Congress, Office of Technology Assessment, July 1981).**

[6]See **General Accounting Office, "Producing More Fuel-Efficient Automobiles: A Costly Proposition," CED-82-14, Jan. 19, 1982.**

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*These data include both domestically produced and imported cars.

[7]**U. S.** *Industrial Competitiveness,* **op. cit.**

turers' weak competitive position is primarily due to high production costs relative to foreign producers and consumers' perceptions of value in domestic v. imported cars, that are difficult to quantify. If a strong demand for fuel efficiency develops, rapidly increasing the fuel efficiency of domestic automobiles could help to sell them. Demand for fuel efficiency, however, is usually accompanied by a shift in demand to smaller cars, the market area where U.S. manufacturers have been least competitive with imports. This shift would therefore also require that domestic manufacturers devote some of their investments to changes unrelated or only partially related to fuel efficiency. Corporate strategy, the way complex investment decisions are handled, overall demand for new cars, and the demand for fuel efficiency vis-a-vis other attributes of automobiles will all interact in a complex way to affect the actual rate at which fuel efficiency increases.

Technological uncertainties will also figure in determining fuel efficiencies actually achieved. These uncertainties relate to the behavior of various elements of the vehicle system, the way in which these elements are integrated and possible performance tradeoffs among elements, and the cost of specific manufacturing techniques. The rate of product and process development, and particularly the success of the development efforts (by no means assured) will influence the extent of fuel-efficiency increases. Basic research could lead to additional fuel economy gains by providing a better understanding of some of the complex processes related to fuel consumption (e.g., nonsteady-state combustion).

The single most important factor limiting the development of electric vehicles (EVS) is battery technology. Even if EVS were to become practical, however, they would not have the potential to displace significant amounts of imported oil, primarily because they would be substitutes for the most fuel-efficient gasoline or diesel-powered cars. The Government could justify accelerating the development and introduction of EVS if the goal is to reduce automobile pollution in the inner cities or to promote a transportation mode that does not use petroleum. EVS are petroleum independent except insofar as electricity is generated from oil.

Automobile Fuel Efficiency— Policy Background

The industry has been regulated by Government policies and programs primarily since the 1960's. Worker and public health and safety aspects are regulated by the Environmental Protection Agency (EPA) and the Occupational Safety and Health Administration; product safety and emissions by the National Highway Traffic Safety Administration (N HTSA) and EPA. Auto sales are affected by all policies that influence consumer demand. In the aftermath of the 1973-74 oil embargo, the Government became actively interested in promoting automobile fuel efficiency, and legislation was subsequently enacted to reduce U.S. dependence on oil imports.

Policy for increasing automobile fuel efficiency is embodied principally in two programs. * The principal policy instrument for increasing fuel efficiency was established by the 1975 Energy Policy and Conservation Act (EPCA) and specifies CAFE (i.e., fleet) standards for new cars and light trucks between the model years 1978 and 1985. Provisions of the CAFE program have generally tried to recognize the financial difficulties of the auto industry. CAFE standards mandate that new-car fuel efficiency will double, incrementally, between the early 1970's and the mid-1980's. (American-made cars had averaged about 14 mpg over the period 1965-75; the 1985 CAFE standards require fleet averages of 27.5 mpg and are to remain in force after 1985.**) Subsequent provisions in the Fuel Efficiency Act of 1980 eased the compliance requirements of the CAFE program, but the basic efficiency standards remain in force. Possible alteration of the standards set by the program for post-1 985 could be a major policy issue coming before Congress.

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a The sources and magnitude of these cost advantages are not well **understood. Understanding the nature of any cost advantages enjoyed by competitors will be critical for determining how, when, and if U.S. manufacturers can get their cost structure into line, See** *U.S. Industrial Competitiveness,* **op. cit., pp. 96-99.**

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*A third program was enactment of the 55-mph speed limit.
**The Energy Policy and Conservation Act provided guidelines for the Department of Transportation to set standards for the early 1980's; Congress set standards for 1978 and 1985.

The second major program, part of the 1978 National Energy Act, establishes excise taxes for purchases of automobiles with low fuel-economy ratings beginning in the model year 1980. Current "gas-guzzler" taxes range from $200 for cars rated at 14 to 15 mpg in model year 1980 up to $3,850 for specialty cars rated under 12.5 mpg beginning in model year 1986. Such taxes raised only $1.7 million in fiscal 1980.9

OTA'S analysis indicates large uncertainties in both economic and noneconomic costs of fuel-economy increases. OTA has also identified uncertainties in demand for fuel-efficient cars as critical to increasing fuel efficiency. These uncertainties, together with the desire of domestic manufacturers to serve a wide variety of consumer tastes with a limited level of capital investment, are mainly responsible for the industry's reluctance to accelerate the development and introduction of fuel-efficiency increases. Until fuel efficiency is a–or perhaps the–major selling point for new car buyers, this reluctance, understandably, is likely to continue.

Factors Affecting the Rate of Synthetic Fuels Production

Unlike increasing automobile fuel efficiency, which may entail restructuring a major existing U.S. industry, production of synthetic fuels involves the emergence of a major new industry. * The costs and therefore the profitability of producing synfuels are influenced by major uncertainties that both characterize the economy as a whole and are specific to the synfuels industry. At the economywide level, factors such as the price of oil, the cost of capital, inflation in general and hyperinflation in the construction industries,

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'Congress rejected 60 proposals to tax purchases of inefficient new cars and 19 proposals to raise gasoline taxes between 1973 and 1977. In 1977, President Carter proposed a stringent "gas guzzler" tax keyed to CAFE standards which included a rebate program for purchases of especially efficient cars (which Congress decided would violate the General Agreement on Tariffs and Trade—or GAIT). When the current excise taxes were enacted, critics argued that they would save only 10,000 bbl/d of imported oil, while the Carter proposal, with higher taxes applied to more vehicles, was estimated to be able to save 170,000 bbl/d (New York *Times,* Dec. 10, 1978).

*The liquid and gaseous fuel industry may also undergo a restructuring, however. Synfuels development will tie up capital in considerably larger blocks and for longer periods than historically experienced by the industry. A concentration of ownership is also likely.

and the availability of appropriate labor and materials will determine the financial risks that must be assumed by investors. Like the auto industry, the synfuels industry is capital-intensive. A moderately sized (50,000 B/DOE) fossil synfuels plant could require an investment of $2 billion to $5 billion; the industry's growth and ability to attract capital will thus be highly sensitive to the investment climate.

The major constraint on the development of a synfuels industry is the technical uncertainty associated with synfuels processes. There is essentially no domestic commercial experience with synfuels processes, and processes and design concepts have not yet been adequately demonstrated at a commercial scale. It is thus conceivable that design errors and unexpected operational problems could delay construction or cause a completed facility to be inefficient, even a "white elephant" operating at only a fraction of its capacity or at greatly higher cost than anticipated. As with any capital-intensive industry, there are high costs associated with the underutilization of capacity.

Synfuels production will bean attractive investment if investors view the technical risks as being low (i.e., commercial-scale demonstration units are successful) and they expect oil prices to rise sharply in the future, or if they want to secure an early market share in case synfuels do become competitive with the oil market. Unless oil prices rise more rapidly than synfuel construction costs, however, synfuels plants may not be economically attractive even after the processes are proven and the technical risk is small.

Synthetic Fuels Production— Policy Background

Congress created the National Synfuels Production Program (NSPP) under the Energy Security Act of 1980 (ESA) to promote the rapid development of a major synfuels production capability. Specific goals are set for 500,000 B/DOE by 1987 and 2 MMB/DOE by 1992.10

0IOs,,th,ti,substitutes for petroleum and natural gas are the focus of the NSPP; other programs support development of synthetic fuels from biomass. Biomass subsidy options have been reviewed in detail in the Office of Technology Assessment's *Energy From Biological Processes.* For the NSPP definition of synfuels see Public Law 96-294, sec. 112 (17) (A).

In the first of three phases, the Department of Energy (DOE) was authorized to offer financial incentives for the production of alternative or synthetic fuels. The original authorizing legislation (Public Law 96-1 26) made about $2.2 billion available, mainly for purchase commitments or price guarantees pursuant to the provisions of the Federal Nonnuclear Research and Development Act of 1974; total funds were subsequently increased to approximately $5.5 billion. ' 11

ESA created the Synthetic Fuels Corp. (SFC) in the second phase as a quasi-investment bank, to provide incentives to promote private ownership and operation of synfuels projects. SFC is backed by funds deposited in a special Energy Security Reserve in the U.S. Treasury and to be used for financial assistance in the form of: 1) price guarantees, purchase agreements, and loan guarantees; 2) direct loans; and 3) support to joint ventures. " The governing board of SFC can decide

which DOE projects it will take over once the board becomes fully operational. Total funds authorized for SFC are approximately $17 billion through June 30, 1984.12

The third phase of the NSPP is to begin in mid-1984, at which time Congress may appropriate an additional $68 billion on the basis of a comprehensive synfuels development strategy to be submitted by the SFC board. SFC is scheduled to lose the authority to make awards in 1992 and to be terminated in 1997. Some revision of NSPP dates, goals, and/or financing may have to be made if the production of synfuels falls short of the original NSPP goals—as is expected. In OTA'S judgment, Congress is unlikely to have sufficient information by 1984 about the technical aspects of synfuels processes to be able to make long-term synfuels decisions.

SFC has received continued political support, and the administration is committed to ensuring the development of a commercial synfuels industry, as announced in its *A Plan for Economic Recovery* (February 1981). In addition DOE has committed about 50 percent of its approximately $5.5 billion, and provisional commitments have been made to two projects. *

Reflecting a recent major policy change however, Government support is now to emphasize long-range, high-risk research and development (R&D) activities that are unlikely to receive private sponsorship. This shift is likely to have different effects on the two main types of synfuels projects: 1) projects designed to test and demonstrate akernative design concepts, learn more about the details of the processes involved, and gain operating experience (demonstration plants); and 2) projects designed to demonstrate commercial-scale process units (CSPUs).

Demonstration plants are generally smaller than commercial-scale plants and are not intended to earn a profit. Under the new policies, DOE programs to support demonstration plants

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"This figure does not include an additional $1.27 billion that has been made available for biomass energy, including alcohol fuels and energy from municipal waste. For further details on this legislation, see Public Law 96-294, Public Law 96-304, and the CRS issue brief (No. MB70245) "Synthetic Fuels Corporation, Policy and Technology," by Paul Rothberg.

During the interim program, DOE awarded, in a first "round," $200 million of these funds, half each for feasibility studies and for cooperative agreements. Of the first $200 million, approximately two-fifths, or $80 million were for biomass projects, while the remainder went to synfuels activities. DOE has in past years also provided support for a variety of research and demonstration activities to support synfuels development.

DOE originally planned a second "round" of awards for feasibility studies and cooperative agreements, but at the request of the Reagan administration the $300 million authorized for these awards was rescinded as an economy measure.

*In its guidelines to investors, SFC indicates that it strongly favors price guarantees, purchase agreements, and loan guarantees, which emphasize "contingent liabilities. " The cost to the Government of such aid varies with the success of the assisted projects; it is minimized when projects produce synfuels that can be priced competitively with other fuels. To prevent overconcentrating funds, SFC can give no project or person more than 15 percent of its authorized funds, which is about $3 billion during its early years (1981-84). In the case of loan guarantees, SFC cannot assume a financial liability for more than 75 percent of the initial estimated cost of the project, requiring the assisted company or companies to risk a sizable amount of their own funds. Although there are broad guidelines, the terms of each award will be negotiated separately with project sponsors.

None of the contingent liability incentives available to SFC can exceed the amounts held for SFC in the U.S. Treasury; that is, SFC cannot "leverage" its funds by guaranteeing loans in excess of its actual reserves. In the period since the passage of the synfuels legislation, estimates of the cost of commercial-scale synfuels plants have continued to increase; therefore, unless investors are willing to negotiate guarantees for smaller percentages of project costs than allowed by legislation, the amount of synfuels produced by the subsidy program may be much smaller than originally anticipated.

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²Synthetic Fuels Corp., "Assisting the Development of Synthetic Fuels," p. 1. The $17-billion figure is an approximation. SFC is authorized to spend up to $2o billion, but the money obligated in the interim program is to be subtracted from the larger figure.

*These are a loan guarantee of up to $1.5 billion to the Great Plains Coal Gasification plant in North Dakota and an as yet un-negotiated assistance agreement with the Union Oil Co, oil shale project (product purchase guarantee).

are being terminated, but these projects presumably can apply to SFC for support.

If CSPUs can be made to operate properly, several such units might be built and operated in parallel in a commercial synfuels plant. Because the process unit is intended to be part of a commercial synfuels plant, support for CSPU demonstrations continues to be available through SFC, under the new administration policies.

Termination of DOE support may lead to cancellation of several demonstration plants, since they must now compete against more developed technologies for SFC support. * This would result in a poorer understanding of various synfuels processes and a narrower range of technology options available to potential investors. It could also reduce the prospects for commercializing plants capable of producing fuels from a variety of coals found in different regions of the coun-

try.13 Finally, processes with the greatest immediate (i.e., not necessarily long-term) commercial promise are likely to be favored by SFC in order to meet production targets. *

Although every commercial-scale process will have gone through a demonstration plant stage, the design of the CSPU will also be based on numerous other sources of relevant information. Terminating demonstration plant projects will reduce this pool of information, thereby increasing the risks that CSPUS will not function properly and reducing the design options for correcting malfunctions. Development of promising longer term synfuels processes may also be delayed or overlooked entirely. For these reasons, it is OTA'S judgment that DOE's termination of support for demonstration plants is likely to reduce the rate at which a synfuels industry is built.

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*Apparently as a result of reduced Government interest in directly promoting synfuels, three projects previously supported by DOE have been canceled (SRC 11 and two high-Btu gasification projects, the Illinois Coal Gasification Project and the CONOCO Project in Noble County, Ohio). Four additional demonstration projects are continuing with reduced levels of DOE support and their futures are in doubt: H-Coal, EDS, Memphis Medium-Btu, and SRC 1. At least one upcoming project, not yet at the demonstration stage, has also been canceled in light of recent developments (a low-Btu Combustion Engineering project).

13See Paul Roth berg, ''Coal Gasification and Liquefaction, '' CRS issue brief No. IB77105, Aug. 12, 1981.

*Legislation calls for SFC to consider a wide range of alternative synfuels technologies in order to broaden industry's experience with the technical and economic characteristics of many processes. This requirement may conflict with the mandate to meet production targets—targets that already appear unrealistic.

POLICY OPTIONS

This section evaluates the major policy options available for displacing oil imports generally and specifically for stimulating auto fuel-efficiency increases and synthetic fuels production. The evaluation is based on the industry characteristics so far discussed and on the technical analysis which appears later in this report. In particular, the impacts of several policy options that have recently received congressional attention are estimated. Note, however, that policies are not discussed in the context of emergency oil shortfalls.

The policy choices available to Congress differ along several key dimensions: 1) the rate and degree of oil import displacement; 2) the degree and specificity of Government intervention and budgetary effects; 3) the types, magnitude, and distribution of benefits and costs; 4) implications for the long-term, sustainable, and competitive health of the affected industries; 5) the relationship of the choices to other Government programs; and 6) the feasibility of future actions. The selection of policy instruments and resulting

tradeoffs will reflect the priority ascribed to each dimension. Policies can generally be designed either as incentives or penalties, incentives more closely approximating the conventional marketplace. Policies can be directed at either economywide or sector-specific measures.

Economywide Level.–''Economywide'' policy choices are concerned with overall economic and business conditions—as measured by such indicators as inflation, unemployment, and interest rates—that determine the financial health, investment climate, and productive capabilities of U.S. industries. Fiscal and monetary policies are the primary instruments in this category; other measures could promote innovation, regulatory reform, technology development, and human resources development. Such Government policies generally seek either to remove or to reduce impediments to a strong and stable economy, as well as to raise business and consumer confidence in the face of changing economic conditions. The advantage of such policies is that they can be directed at many industries, although they will have different impacts on the various affected industries. They are most commonly preferred as a complement to market forces, because their scope enables them to enlist the broadest base of support, and they are best equipped for integrating a wide range of economic and social objectives. General economic policy, however, has only limited ability to promote the displacement of oil imports and to stimulate specific actions, and may indirectly distort capital flows among oil displacement alternatives.

Automobile fuel efficiency and synfuels production (as well as fuel switching and conservation in stationary applications) are influenced by such economywide factors as high interest rates, tight credit, increasing resource costs, and changes in real disposable income. As for the auto industry, general economic conditions influence the ability of consumers to buy cars and the ability of manufacturers and suppliers to invest in needed changes. General economic policy could help to stimulate demand for automobiles by lowering the costs of consumer credit and by making credit available. Strong demand for new cars, together with stimuli that reduce the effec-

tive costs of capital and retooling can, in turn, stimulate the supply of fuel-efficient automobiles.

Economywide measures, however, would not induce consumers to buy domestically manufactured vehicles rather than imports; and they could have a mixed effect on local automobile production and employment. Economywide measures may facilitate investments by foreign firms in U.S. facilities, but they also assist investments by local producers in labor-saving equipment and investments by domestic manufacturers in low-cost production facilities abroad. These investments may ensure the financial health of individual, American-owned firms, but attendant reductions in domestic employment may aggravate regional economic problems.

Deployment of synfuels production capacity will also be sensitive to general economic conditions: interest rates not only influence the availability of capital for building plants; the capital costs also help determine whether products can be priced competitively. Once established, however, the synfuels industry is expected to be relatively insensitive to general economic conditions to the extent that synfuels are indistinguishable from conventional fuels and are competitively priced, and the plants do not require frequent retooling. Based on the analysis provided in this report, it is OTA'S judgment that favorable economywide conditions, by themselves, are still unlikely to provide sufficient incentive for private firms and investors to accelerate the commercialization of a synfuels industry because of the large technical risks associated with as yet commercially unproven synfuels processes.

Sector-Specific Level .–Policies can be aimed at specific industries to stimulate industrial competitiveness, ease the adjustment of firms to new economic conditions (rapid growth, short-term distress, or long-term decline), or to promote the achievement of national or regional objectives (e.g., national security, regional development). To formulate policies at this level, analyses of individual sectors and linkages among sectors are essential. The major disadvantages of such policies are that they do not always address the underlying causes of market distortions and they discriminate against other industries which are

not similarly assisted. in terms of the auto industry, sector-specific policies would be most effective if they addressed the market risk, which is a major factor determining the rate of fuel-economy improvements. The major constraint on rapid deployment of a synthetic fuels industry is technical uncertainty with respect to unproven processes and, currently, the cost of conventional oil products.

Economywide Taxation—Oil and Transportation Fuels

General taxation measures are one vehicle for stimulating capital investment across the economy. Economywide taxation measures that specifically relate to displacing oil imports are taxes on oil imports, on oil in general, and on transportation fuels (e.g., gasoline and diesel fuel) in particular. To the extent that the Nation's energy "problem" is defined as dependence on insecure foreign sources, an oil or transportation fuel tax would promote security by reducing oil demand. However, an oil or gasoline tax could be counterproductive to the degree that the energy "problem" is defined as a lack of relatively low-cost, high-quality fuels. Consumers may oppose an oil import tax, even though its impact would be minor compared with that of large OPEC price increases, as was the case when an oil import tax of $0.33/bbl was in effect briefly during the Ford adminstration. Its impact, if any, was minor in comparison with that of OPEC's hikes.

Oil taxes can be imposed either on oil generally or on oil imports in particular. The advantages of an oil tax arise because of three features. First, the tax would make all uses of oil more expensive without prejudging which kinds of adjustments would be most desirable. A general tax on oil would thus reduce consumption and, in turn, imports. Second, the tax could be designed to isolate consumer oil prices from reductions in international oil prices. For example, if OPEC prices remain steady through 1984 and if inflation continues at current rates, the real price of oil could decline by as much as 20 to 30 percent during this period. While perhaps beneficial to consumers in the short term, declining real prices for petroleum products would probably lead to in-

creased petroleum demand. Consistent price signals would also provide assurance both to the auto industry that demand for fuel-efficient cars would be at least sustained if not increased, and to synfuels developers that they would receive at least a constant real price for their products. Finally, tax revenues could be used, for example, to support import displacement investments, or to offset some of the potential adverse effects of the tax (e. g., to fund income support programs).

Taxing only crude oil, however, and not its products could reduce the international competitiveness of industries heavily dependent on oil—such as refineries and petrochemical companies. * Furthermore, because oil taxes do not differentiate among industries that use oil, they are not effective means of altering the competitive position of either automobile fuel economy or synfuels production relative to any other method for displacing imports (if such alteration is desired). Such taxes could also contribute to inflation generally and would be paid for disproportionately by consumers with low incomes. Compensatory programs and payments could deal with such side effects, but at additional implementation and administrative expense.

Taxes targeted at only oil imports could discriminate against companies, and regions of the country, that are heavily dependent on imported oil. It is more likely, however, that import taxes would cause the general price of oil to increase to a level close to the price of taxed imports. Any general price increase, in turn, would create additional revenues for domestic petroleum produc-

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*It is possible that refining activities would relocate overseas unless additional import restrictions were also imposed. With respect to synfuels production, refiners might be able to cut profit margins and continue to process and sell oil at prices below synfuels prices in order to maintain refining volumes (which are already rather low). Because many old refineries do not have capital charges, refining costs would be dominated by the variable costs of about 15 to 20¢/GALproduct plus the oil acquisition costs. Consequently, taxes may have to raise the cost of imported oil to within about $6/bbl of synfuel product (150gal of gasoline equivalent) to ensure that the refiners cannot economically use oil imports as copetitors for synfuels. This would directly harm some companies ened in oil refining, but this may be a necessary tradeoff to ensure that synfuels actually displace imported oil, rather than act to reduce domestic petroleum product prices and thereby discourage a reduction in domestic oil consumption.

ers. The total revenues generated by an import tax would thus be only partially received by the Government. Compared with a general oil tax, an import tax is thus likely to result in a smaller fraction of revenues being available to the Government for additional import displacement measures or to offset any adverse impacts of higher oil prices. The windfall profits tax captures some additional revenue, but is more complex to administer than a general tax on all oil.

Another disadvantage of an import tax, frequently discussed, is the possibility that oil exporting nations might see the acceptance of added cost by U.S. users as an indication that their crude prices could be further increased without reprisal or economic hardship. This objection probably is not valid, however, during times of crude oil surplus in the producing nations.

With respect to transportation fuel consumption, a tax either on oil or on transportation fuels reduces demand for all uses of transportation fuel, including automobile travel, as well as increasing the relative demand for fuel efficiency. It could reduce new-car sales, however, and could also reduce the profitability of truck transports, agriculture, airlines, tourism, and other fuel-dependent industries. Taxes on only gasoline would avoid some of these problems, but they could encourage the purchase of diesel-fueled automobiles.

Gasoline taxes in this country have increased only slightly during the past two decades.l A The Federal tax has been $0.04/gal since 1960, while the average State tax has increased from $0.065 to $0.08/gal. A gasoline tax that increased the price of gasoline by, say $0.05/gal (i.e., a 3-percent increase over a $1.50 price) would raise about $5 billion per year at current consumption rates, as would a $1 .00/bbl crude oil tax. I n order to offset inflation since 1960, the current gasoline tax would have to increase by about $0,1 5/gal. Taxes on gasoline are significantly lower in the United States than abroad. *

The ultimate effect an oil, gasoline, or diesel fuel tax would have in displacing oil imports depends on at least three factors. First, the effectiveness of the tax in the long run depends on the actual purchase and use of fuel-efficient vehicles. Estimates of the responsiveness of demand (its "elasticity") to changes in gasoline, auto, and other prices vary widely from study to study, but they suggest that a tax on crude oil or transportation fuels would have to be relatively large to motivate consumers to trade in their relatively inefficient cars for more efficient ones. ' [5]Note, however, that tax provisions per se would not differentiate between domestic and foreign manufacturers except insofar as one produces more fuel-efficient vehicles.

Secondly, tax impacts will depend on final oil or fuel prices. The entire tax amount need not be passed onto consumers if producers are able to maximize profits by lowering the price of gasoline, absorbing part of the tax, and increasing sales. As long as demand for oil is slack relative to supply, at least part of the tax will be absorbed by producers.

Finally, the effect of taxes will depend on the degree to which driving is reduced. While OTA'S analysis of oil savings attributable to fuel economy improvement assumes a steady increase in vehicle miles traveled (VMT) (but a drop in VMT per capita), lower total VMT induced by high gasoline prices would increase actual oil savings. * However, this could also reduce car sales.

While gasoline stations and refineries would be affected by reduced demand, industry analysts already expect that the number of service stations and refineries will decline in the 1980's. Remain-

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IsDemand response is difficult **to quantify because there is only limited past experience with periods of gasoline price increases ("preenergy crisis" conditions appear to be of limited value for predicting "postcrisis" consumer behavior); crude oil and transportation fuel prices affect consumers in dynamic, multiple ways to alter real income and demands; and it is difficult to understand demand response when vehicles have many different attributes, of which fuel efficiency is only one. (See** *Motor Vehic/e Demand Mode/s: Assessment of the State of the Art and Directions for Future Research,* **prepared by Charles River Associates, Inc., for the U.S. Department of Transportation, April 1980.)**

*For example, OTA estimates that about half of the 0.5 MMB/D reduction in gasoline consumed by autos in 1978-80 was due to reduced driving, while about half was due to increased efficiency of vehicles in use.

~4S*ee Hans H. Landsberg, Energy Po/;cy* **Tasks for the 1980s, RFF reprint 174 (Washington, D. C.: Resources for the Future, 1980).**

*Taxes on gasoline (per gallon) in 1979 were, as examples, $1.59 in France, $0.88 in the United Kingdom, $1.14 in West Germany, and $1.58 in Italy.

ing stations and refineries should be financially stronger and better able to adapt to gasoline price increases. Any reduction in highway trust fund revenues could presumably be balanced by proceeds from the gasoline tax or other taxes.

Economywide Taxation— Special Provisions

Special taxation provisions are often applied at the economywide level to promote investment (e.g., by encouraging capital formation and restructuring cashflow positions). Examples of such provisions are investment tax credits, depreciation allowances, R&D tax credits, and capital gains. As with other taxes, special taxation provisions could have differential impacts on industries and distort private returns to capital. Both the auto and synfuels industries (as well as the electric utility industry), being capital-intensive, could benefit from special taxing provisions. The scope for additional special taxing provisions, however, is believed to be limited because of the many existing provisions,

Although a firm would generally have to be profitable to take advantage of special taxation provisions, tax credit sales rules have been expanded and liberalized to give unprofitable firms the chance to sell their investment tax credits and depreciation rights. The auto industry has already taken advantage of liberalized rules for selling tax credits.lb This type of sale can help to strengthen the financial position of the auto industry, although it does not directly encourage increased fuel economy.

It is speculative to analyze how special taxing provisions would stimulate investment in synfuels. Special taxing provisions have historically been applied at the sector-specific level for domestic oil producers in the form of special depreciation allowances, and currently for expensing drilling costs and for foreign tax credits.

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[16]For example, Ford Motor Co., with losses in excess of $700 million in 1981, sold its tax credits on 1981 equipment purchases for somewhere between $100 million and $200 million to IBM (*Washington Post,* Nov. 11, 1981).

Research and Development

Government policies and programs could stimulate technical R&D at either the economywide or sector-specific levels to help displace oil imports. The primary rationale for Government support of R&D is that there are social benefits from R&D which surpass private gains, in large part because of high front-end learning costs. in addition, the Government tends to support research that is too risky for private funding, and which does not, for a variety of reasons, attract private investment in the short term. A major advantage of Government support for R&D is that programs can assist the economy, and specific industries, without direct intervention. However, the types of basic research that Government has traditionally supported often have benefits only in the long term, so a nearer term oil import savings implies Government involvement in shorter term R&D areas. Applied R&D also offers the opportunity for the Government to acquire equity in projects or royalties from the results of the R&D.

EconomyWide R&D support could be designed to stimulate opportunities for displacing oil imports generally and for both increasing automobile fuel efficiency and accelerating synfuels production. Such measures could, as examples, sponsor basic research, promote the climate for technical innovation (e.g., increasing the rewards to innovators through patent laws and/or special tax incentives), or establish mechanisms for assembling and disseminating technical information. Such nonspecific support, however, is unlikely to have much impact on resolving the specific technological uncertainties that impede both auto fuel-efficiency increases and synfuels development.

Although the Government has supported sector-specific R&D in the past, policies have seldom supported product development with direct commercial application except in agriculture and nuclear power. Research to increase automobile fuel economy and to develop synfuels, as well as other technologies for displacing oil imports, would have direct commercial application.

There has not yet been any substantial Government support for R&D to assist the automobile industry. Several R&D and technology demonstration programs have been Government-sponsored, and a joint industry-Government-university R&D program (the Cooperative Automotive Research Program) was attempted unsuccessfully in 1979-80.[17] Some of the basic research areas that could result in substantial long-term fuel-economy payoffs include:

1. the engine (e.g., advanced alcohol-fueled engines, nonsteady-state combustion, microprocessor controlled fuel injection, high-temperature materials);
2. vehicle structure (e.g., crashworthiness);
3. aerodynamics;
4. friction, lubrication, and wear;
5. innovative production technologies for lightweight materials; and
6. exhaust emissions.

The Government might also continue to provide some support for the advanced development of electric and/or hybrid vehicles, alternative engines, and alternative automobile fuels.

The technical uncertainties associated with synfuels development are substantial. It is OTA's judgment that, even in the presence of favorable economywide conditions, investors would not have sufficient incentive to accelerate synfuels development because of the magnitude of the technical risks associated with process technologies. For example, one of the major components of technical uncertainty is concerned with the flow and abrasive properties of solid/liquid process streams. Gaining a basic understanding of the properties of these streams so that equipment will function properly is both a theoretical and an empirical engineering challenge. At present, engineers must proceed to full-scale commercial plants without adequate analytical descriptions of how well designs will work. OTA believes there may be considerable benefit in continuing the original concept of a demonstration program to provide technical information. The results of both

basic and applied research could lead to important near- and long-term advances in synfuels technology, as well as in other technologies concerned with solids handling.[18]

Trade Protection

Trade protection–tariffs and duties, quotas, local content requirements—has economywide implications but has traditionally been used to temporarily insulate specific industries and products from foreign competition. The case for import protection for the domestic auto industry is based on the claim that the industry requires only temporary protection in order to increase sales and thus to improve its revenue position, to generate capital for reinvestment, and to position itself for manufacturing fuel-efficient cars. On the other hand, it is argued that temporary trade protection would neither ameliorate the shot-t-term competitive problems of the industry nor promote long-term restructuring for fuel economy. It is seen as inefficient and indirect adjustment assistance that can lead to higher consumer prices due to reduced competition, to higher production costs for those industries that must compete, unsubsidized, against autos for resources, and to less innovation in general. Trade protection could also lead to retaliation on the part of trading partners, and some measures are restricted by the General Agreement on Tariffs and Trade (GAIT).[19]

Import quotas are generally considered less efficient than tariffs in reducing imports and stimulating domestic industries. This inefficiency arises because quotas directly distort both production and consumption (whereas tariffs change relative prices), and quotas can be bypassed with product differentiation. Duties have not generally figured in the policy debate, * but U.S. auto manufacturers have been granted temporary trade protection in the form of a 3-year Japanese automobile quota agreement. The ultimate effects of

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[17]The **Justice Department also recently agreed to ease restrictions which had barred the four major manufacturers from working together on development, as well as sale and installation, of pollution control devices. See** *The Washington Post, Nov.* **10, 1981.**

[18]*See also* "Report to the **American Physical Society by** the Study **Group on Research Planning for Coal Utilization and Synthetic Fuel Production,"** Rev. *Mod. Phys, 53, 4* **(pt.** *2),* **October 1981.**

[19]" **General Agreement on Tariffs and Trade, "** 55 U. *N.T.S.* **194,** T.I.A.S. **No. 1700 (1947).**

*Duties on car imports into the United States are 6 percent; this compares with 14 percent into Canada, and 11 percent into France, Italy, Germany, and the United Kingdom.

these **quotas on the domestic industry** are un-known, but thus far the impacts of import restraints appear to be small due to low new-car sales. However, if new-car sales recover, the prices of all small cars could increase to the extent that shortages are artificially induced by the trade restrictions.

Local content provisions are another form of trade protection that has been discussed in the context of the domestic automobile industry (H.R. 51 33). These measures would not displace oil imports directly but **could** help to protect domestic automobile manufacturing jobs. Such provisions are generally viewed as being economically inefficient, although they could serve other social/equity objectives.

Trade protection is not likely to address any of the major issues on which the future of the synfuels industry depends. Trade concerns may eventually arise if large quantities of materials and equipment are imported to construct synfuels plants or if the United States is in a position to export synfuels products or production experience.

Trade protection could be used to limit oil imports directly. Such a quota, however, could lead to domestic shortages and price increases in the absence of replacements. The Carter administration placed a quota on oil imports (and explored alternatives for allocations within the United States should demand exceed the quota), but it was set at a level which did not influence imports. import quotas were also in effect from 1959 to 1971.20

Sector-Specific Demand Stimuli— Purchase Pricing Mechanisms

Demand for increased automobile fuel economy is an extremely important factor influencing the rate of increases in new-car fuel efficiency. Autos are large, long-term, and deferrable investments for consumers. Furthermore, the decision to buy a particular car depends on many attributes, of which fuel economy is only one. Imported oil will not be displaced by the man-

ufacture of more fuel-efficient cars unless these cars are actually bought. Demand uncertainty can be reduced, and the demand for fuel-efficient cars can be stimulated, by raising the costs to consumers of buying and operating inefficient cars and/or by lowering the costs of owning relatively efficient ones. The risks to manufacturers of producing fuel-efficient cars could thus be reduced. Car ownership costs can be altered by taxing gasoline, as discussed, or by taxing/subsidizing automobiles directly.

Synfuels per se should not be directly influenced by consumer behavior except insofar as weak demand for liquid fuels limits the profitability of synfuels production. Some synfuels, however, may not fully conform to end-use fuel specifications without more extensive processing or end-use equipment modifications. The extent of this potential demand problem cannot be determined in the absence of end-use testing, but is likely to be minor except for alternative fuels such as methanol.

Purchase Taxes and Subsidies

Automobile purchase taxes or price subsidies can directly change the costs of owning cars of differing fuel efficiencies. Purchase pricing mechanisms can be linked either implicitly or explicitly to fuel-efficiency performance criteria. Current taxes are now only loosely related to CAFE standards. The extent to which additional measures would discourage the purchase of inefficient cars, or encourage the purchase of efficient cars, depends on many factors, including the level of the effective tax (or subsidy), the range of vehicles affected, the extent that auto manufacturers' pricing policies counteract the effect of the taxes (or subsidies), and the responsiveness of consumer behavior to changes in car prices. * There is also

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“"'Energy Policy," 2d cd., Congressional Quarterly, Inc., Washington, D. C., March 1981, p. 30.

*The difficulty in quantifying elasticities (i.e., the percentage change in demand for a l-percent change in price) is discussed in "Economywide Taxation—Oil Imports and Gasoline. " The international Trade Commission analysis of the Carter gas-guzzler tax proposal implied an elasticity of demand for subcompacts of –0.79 (i.e., sales of subcompacts increase less than proportionately with decreases in their prices) and an elasticity of demand for full-size cars of – 1.12 (i.e., sales of full-size cars decrease more than proportionately with increases in their prices). Assuming that these figures are accurate, to reduce full-size car sales by 50 percent, for example, their prices should be raised by about 45 percent, or at least $3,500.

some risk that price subsidies targeting only domestic vehicles could violate the GATT provisions which prohibit most-favored-nation trading partners from taking actions that discriminate against imports from one another.

Low-interest loans for consumers could stimulate the purchase of all new cars, which are generally more efficient than the average car on the road. By tying the interest rates to the new car's fuel efficiency, sales of the more fuel-efficient new cars could be stimulated.

Gas-guzzler taxes, as another type of pricing mechanism, would reduce the demand for relatively fuel-inefficient cars. However, because such taxes do not discriminate among different types of users, **a** disproportionate share of the taxes could be paid by those who are most constrained to using large vehicles. An equity argument can be made for excepting certain classes of drivers in a tax program (e.g., taxis, hearses), Income support programs could aid in the cases of financial hardship; and tax proceeds could be used to fund these relief measures.

Both purchase subsidies and taxes may additionally and at least temporarily strain the revenue position of U.S. automakers because they are the principal suppliers of large cars, but subsidies could strengthen their long-term position due to increased car sales.

If Congress wishes to avoid discrimination against large cars (which are inherently less fuel efficient than small cars), purchase taxes or subsidies could be based on the fuel efficiency of a given model relative to other models within the same size or market class. This type of approach would lead to numerous cases where less fuel-efficient cars are taxed at lower rates or subsidized at higher rates than the more fuel-efficient ones, but it would create a demand for cars with less powerful engines and technologically improved cars (as opposed to simply smaller ones) and it would not favor imports in most cases.

Bounties

Another way to use purchase pricing mechanisms to stimulate rapid fleet turnover to higher fuel economy is by offering a gas-guzzler boun-

ty. Bounties could be designed, as examples, as full payment for a trade-in, or as a payment upon proof of scrappage of a fuel-inefficient car. Because consumers are relatively unresponsive to changes in prices,[21] the bounty would have to be large to induce significant increases in sales of more fuel-efficient cars. For example, if a value of **–0.3** is assumed for the price elasticity of demand for new cars, then for total new car sales to rise by 10 percent, net prices would have to fall by one-third. Since the average new car costs about $8,000 in 1980-81, a bounty of about *$2,700* would be necessary on average to raise new-car sales by 10 percent. Since many used cars have market values under $2,700, this scheme would be profitable for the owners of used cars. However, it would be costly both to the Government and to potential buyers of used cars.

The bounty price would become the effective minimum used-car market price and all used-car prices would be proportionately increased. Because bounties distort existing relationships and operations of both the new and used car markets, bounties would be difficult to design and implement efficiently. Unless bounties were tied to high-fuel-efficiency car purchases, they might neither help manufacturers nor lead to significant fuel savings.

Registration Taxes

Car registration taxes represent another demand-side stimulus. These taxes would affect the owners of all automobiles, and they could be explicitly tied to fuel efficiency or some surrogate measure* to encourage replacement of fuel-inefficient cars. However, they would make auto ownership more expensive regardless of the amount and nature of the travel, and they would work towards reducing demand for autos in the long run. By effectively lowering consumer income, registration taxes would also disproportionately

[21] **"Motor Vehicle Demand Models: Assessment of the State of the Art and Directions for Future Research, " prepared by Charles Rivers Associates, Inc., for U.S. Department of Transportation, April 1980.**

*One possible measure would be ton miles/gallon (e.g., how much a vehicle weighs per rate of fuel use), Several foreign countries already have registration taxes that depend on automobile weight and/or engine size.

affect low-income groups. * In addition, a registration policy implies State action, and consistent, concerted implementation may be difficult to achieve.

An important possible side effect of all demand-side stimuli which have the effect of reducing large-car demand is that only those domestic manufacturers with a clear competitive advantage in producing large cars will continue to serve this shrinking market. This reorientation of domestic production would be consistent with long-term international trends towards corporate consolidation and a standardized "world car. "

Methanol

Promoting the use of methanol as an automobile fuel is likely to require coordination of supply and demand stimuli. A limited supply of methanol, however, is currently available from the chemical industry. * *

Automotive uses of fuel methanol are principally in a blend (with cosolvents) in gasoline or in engines designed or converted to use straight (neat) methanol. Because many automobiles now on the road cannot accept methanol-gasoline blends with more than 1 to 3 percent methanol, the blend market for methanol is currently quite limited (less than 50,000 B/DOE); but the potential market could be expanded if incentives were provided to make new cars compatible with higher percentage blends. This would also add flexibility with respect to matching supply and demand, which would help to avoid methanol fuel shortages and gluts. The use of blends could be encouraged through direct subsidies and through approval of methanol by EPA as a blending agent in gasoline.

Demand for fuel methanol can also be stimulated with incentives to convert captive fleets*** (current fuel consumption by larger fleets is about

0.6 MMB/DOE[22]) to methanol. Captive fleets are currently more attractive for neat methanol use than privately owned cars because fleets often have their own fuel storage and pumping facilities, which can be converted to methanol at the same time as the fleet conversion.

Introduction of vehicles for general use which are fueled with neat methanol probably will require coordinated planning to ensure that neat methanol is available at service station pumps at about the same time or before the vehicles appear for sale. However, if this fuel supply problem can be solved (see supply stimuli below) and methanol is available at prices (per Btu) comparable to gasoline, it is likely that some auto manufacturers will supply alcohol-fueled vehicles without Government incentives.

Sector-Specific Supply Stimuli— Subsidies and Guarantees

Supply-oriented stimuli–in the form of direct subsidies, grants, and loan, price, and purchase guarantees–are methods for quickly providing visible and directed sector-specific support to industries and firms.[23] These stimuli, by shifting a portion of the costs and risks to the Government, can provide a temporary inducement to firms to accelerate investments (i.e., to the auto industry to increase fuel economy and to the synfuels industry to accelerate production). Supply-oriented stimuli can also be structured so as to minimize or alleviate costly side effects associated with the investment or stimulus. The rationale is that market-driven business practices would not provide, at the time required, nationally desirable output levels.

Sector-specific, supply-oriented policy measures share the disadvantages described earlier that are associated generally with any sector-specific policy approach. In addition, they could put direct pressure on the Federal budget. De-

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*other fees that could discourage fuel use by all drivers include commuter taxes, car-pooling incentives, and parking fees.

**Total U.S. methanol production, which comes from natural gas and residual fuel oil, corresponds to about one *50,000* B/DOE synfuels plant or about 1.5 billion gal of methanol per year.

***A captive fleet is a fleet of cars or trucks owned and operated by a single business or Government entity and often used primarily in a localized area with central refueling facilities also owned and operated by the fleet owner.

[22]The Department of Energy ("Assessment of Methane-Related Fuels for Automotive Fleet Vehicles," DOE/CE/50179-1, vol. 2, pp. 5-23, February 1982) has estimated that automobile fleets of 10 or more, truck fleets of 6 or more, and bus fleets consume about 0.6 MMB/D of gasoline and about 0.4 MMB/D of diesel. Replacing all of the gasoline would require about 20 billion gal of methanol per year.

[23]See An Assessment *of Oil Shale Technologies,* OTA-M-118 (Washington, D. C.: U.S. Congress, Office of Technology Assessment, June, 1980).

tailed analysis is required to ensure that policies and programs do not perpetuate inefficient operations, that production changes and other efficient innovations are not being discouraged, and that targeted manufacturers are not benefiting inequitably. A major implementation problem is in linking of payment with performance: to ensure that supply-oriented mechanisms promote oil displacement, they would need to be contingent on savings or production performance. Ideally, a detailed study of the many factors that determine fuel use could illuminate how much stimulation would be required to reduce oil imports and how such measures would affect the Nation's energy bill. In practice, however, any such study is likely to have numerous shortcomings and inaccuracies.

Loan Guarantees and Grants

The principal sector-specific supply-oriented policy mechanisms are loan guarantees, price and purchase commitments, and direct grants. Of these, grants are the most advantageous for investors, since they are a form of direct assistance. Grants for improving auto fuel efficiency and producing synfuels may be unpopular because both alternatives are sponsored by the private sector and have profit-generating potential. Objections to direct grants could be offset somewhat if the Government purchased equity in the companies with the money.

Loan guarantees are also advantageous to investors because they allow investors to reduce their financial exposure in case of default. Unlike grants which require that the Government appropriate funds immediately, loan guarantees require Government payment only in the event of a company's default. Loan guarantees have been applied to both the auto and synfuels industries. In the case of autos, loan guarantees were administered by the Government to the Chrysler Corp. when it judged that the costs of **not** intervening would be unacceptable from a national viewpoint. These loan guarantees represent a break with historic policy. No direct aid had previously been given because the industry as a whole was profitable and there was a reluctance both on the part of the Government to subsidize the private sector (except under unusual circum-

stances) and on the part of the private sector to accept Government support and related conditions.

Three policy complications also would arise when considering subsidizing domestic auto manufacturers:

1. determining the eligibility of foreign firms that establish production subsidiaries in the U.S. (e.g., Volkswagen of America, Honda);
2. compliance with GATT provisions; and
3. the treatment of auto suppliers. *

Loan guarantees are administered by SFC under ESA for the synfuels industry. These guarantees have been justified on the basis that the costs and technical risks of synfuels production are so great that, in the absence of loan guarantees and other supply-oriented stimulation, private investment would be slow in coming. With the large (75 percent) guaranteed loans that are possible under ESA, investments in synfuels appear to be attractive. * * industry has generally favored Government support in the form of loan guarantees to stimulate investment, and OTA believes that this is an effective way of making synfuels investments financially attractive.[24] Because of general inflation and steady increases in the estimated costs of synfuels projects, however, the funds currently available to SFC and the limitation of about $3 billion in aid per project may not be adequate to support the number of projects originally envisioned or allow a full 75-percent loan guarantee for the larger projects.

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*Although many suppliers will have to invest to accommodate automotive change, it may be most efficient to subsidize only manufacturers, who would in turn, fund suppliers as appropriate, for two reasons: first, the amount of U.S. supplier investment (and to a lesser degree U.S. manufacturer investment) depends on the amount of outsourcing and the degree to which foreign supplies are used; and second, it is easier to deal with the handful of manufacturers than the thousands of suppliers they may use.

**The 61 proposals received by SFC in its first general solicitation are a preliminary confirmation of this. These proposals reflect the variety of approaches considered viable by private industry: 14 oil shale projects, eight tar sands (including heavy oil) projects, one coal-oil mixture project, one solid-fuel additive from coal project, and one hydrogen-from-water project. Of course, general economic conditions, as well as the price of imported oil, will also have a major impact on the decisions of private investors. These conditions will, in turn, heavily influence the terms that SFC is able to negotiate as it seeks to employ the funds available to it.

[24]Ibid.

Purchase and Price Guarantees

Purchase and price guarantees protect investors by ensuring that products can be sold at a price equal to or greater than the minimum guaranteed, regardless of market conditions. But unless the price is set at extremely high levels, these incentives do not ensure against losses that occur if initial estimates are wrong with respect to cost, price, production volume, or product quality. These guarantees are most appropriate when market demand and price are the major uncertainties (and are expected to be "too low"), where commodities are homogeneous, and when commodities have a value to the Government in use or resale. They could, however, distort relationships among producers and consumers; they can be administratively complex, and they do not reduce investors' financial exposure in the case of poor performance.

Purchase and price guarantees have generally not been considered viable for the auto industry because of the differentiation of its products and the complexity of manufacturer-dealer-consumer relationships.

Although purchase and price guarantees do not address the central technical uncertainties of synfuels production, they may nevertheless be useful in conjunction with other incentives. Provisions for price guarantees and purchase commitments are included in the 1980 synfuels legislation.

Subsidies and guarantees can lead to large annual investments by the Government. For example, given that 6 to 8 million cars are produced domestically each year, subsidies of several hundred dollars per car for fuel-economy improvements (which corresponds to the investments needed to make the necessary changes) could require annual expenditures of several billion dollars.

To illustrate the magnitude of subsidy that could be necessary through a price guarantee to accelerate synfuels production, assume that crude oil costs $40/bbl, that synfuel from a newly opened 50,000 B/DOE plant requires a $10 subsidy for each barrel of oil replaced, and that synfuels production costs follow general inflation. if the real price of oil were to escalate by 2 percent per year, the synfuel would have to be sub-sidized for 11 years at a total cost of about $1 billion. If the real price of oil escalates at 4 percent per year, the period of subsidization and the total cost would be half as large. Similarly, a 1-percent real inflation rate for oil would double the duration and magnitude of the subsidy. Thus, price guarantee subsidies can reach levels that are a significant fraction of the investment initially needed to build the plant.

The Government could, however, require repayment of a subsidy if the manufacture of fuel-efficient cars or the production of synfuels became profitable without subsidies.

Methanol

The supply incentives mentioned above and those described under "demand stimuli" are probably adequate to encourage production of methanol from coal for use by the chemical market and some captive fleets of automobiles, and, possibly, as blends in gasoline. However, additional supply incentives may be necessary to encourage the use of methanol in automobiles which are not part of a captive fleet.

Once significant quantities (probably more than 0.1 to 0.2 MMB/DOE) of methanol are being used in captive fleets and, possibly, in gasoline blends, it may be possible to offer methanol for sale to the public in enough places to make ownership of a methanol-fueled vehicle practical for individuals. Incentives can be offered to owners of methanol-fueled captive fleets, who have their own methanol storage and pumping facilities, to sell methanol to the public. Incentives can also be given to service station owners who sell methanol blends to install methanol storage tanks and blend the methanol with gasoline at the pump. They could then sell straight methanol, as well.

Many owners of captive fleets probably cannot be easily induced to offer methanol for sale, because it would not be related to their other business activities and would be tantamount to entering the service station business. Similarly, very large economic incentives may initially be necessary to induce service station owners to install methanol facilities, because the investment would not lead to a near-term increase in sales.

On the other hand, it could be mandated that any supplies of methanol used for Government-owned captive fleets be made available for public sale. And some captive fleet and service station owners would be willing to offer methanol to gain an early market share or for the financial incentives offered by the Government. If these monetary and nonmonetary incentives were adequate, methanol could compete directly with gasoline and diesel fuel as an automobile fuel.

Regulations on Output

One of the most direct policy mechanisms for promoting alternatives that can displace oil imports is regulation. Regulations are a common, if controversial, form of Government intervention in the economy. Although their effects can be felt economywide, regulations are typically directed at specific industries or products. In general, they would target the supply aspects of oil import alternatives. Measures could also be designed to target consumers (e.g., the 55-mph speed limit, end-use fuel restrictions in the stationary sector), but the Government has traditionally been reluctant to mandate changes in consumer behavior and habits.

Regulations can be designed for two major purposes. First, they can serve to protect the public from the side effects caused by the conduct of industrial activities. These effects include impacts on the environment, health, and safety which are discussed in the next section. Regulations can also be used to determine outputs directly—the level of consumption or production of fuels–if the market is unable to ensure desirable levels.

The auto industry has been regulated in the United States in the areas of emissions, safety, and more recently fuel economy. The major Government program mandating fuel-efficiency increases is the CAFE standards. Whether or not to increase these standards beyond levels set by current legislation for 1985 and beyond may be a major upcoming decision before Congress.

Effectiveness of the CAFE standards in spurring fuel economy improvements is controversial, An important feature of these standards is that they are effective only if they force manufacturers to do more than consumers demand. This increases

the investment risks since, although regulations can affect the supply of fuel-efficient cars, they do not directly influence purchases. Through the 1970's consumers failed to demonstrate a consistent demand for fuel economy, * and the CAFE standards probably increased fuel efficiency above what the market would have achieved. And recent data (fall 1981) show that, in fact, the proportion of relatively large cars sold has once again increased compared with the number of smaller cars sold.

The arguments for extending CAFE standards beyond 1985 are inconclusive. To the extent that CAFE standards are met through sales of smaller cars, as opposed to purely technological changes, U.S. manufacturers must increasingly compete with imports for the small-car market. Increasingly stringent fuel economy standards could, therefore, result in higher import levels if domestic manufacturers are unable to increase their competitiveness in this market, despite the product changes they have made. Post-1 985 standards are also likely to require additional capital for more rounds of redesigning and retooling. But post-1985 standards could result in important fuel savings to the Nation, especially if the demand for fuel-efficient cars remains sluggish. Additional demand stimuli may also be necessary, depending on national and international conditions, to ensure that fuel-efficient cars are bought.

In considering the effects of CAFE standards it is important to recognize that CAFE standards do not distinguish among average efficiency increases that result from: 1) technological improve-

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*The drop in demand for fuel efficiency and the resurgence in large-car demand in the mid to late 1970's led manufacturers to petition (unsuccessfully) NHTSA to lower CAFE standards for the early 1980's because sluggish sales of fuel-efficient cars made necessary investments appear especially costly and risky. Market trends in the 1970's also led manufacturers to concentrate initially on improving fuel economy for relatively large cars rather than on developing new small-car designs. Manufacturers attributed their expectation to exceed voluntarily the 1985 CAFE standard of 27.5 mpg to renewed, strong demand for fuel economy arising from the 1979 oil crisis and increases in gasoline prices. This increase in demand and current industry efforts to raise fuel economy recently led NHTSA, which administers the CAFE program, to terminate rulemaking with respect to post-1 985 average fuel-economy improvements *(Fed. Reg. 22243,* **Apr. 16, 1981). A petition from the Center for Auto Safety that requested NHTSA to continue rulemaking was also subsequently denied** *(Fed. Reg. 48383,* **Oct. 1, 1981** *).*

ments, 2) consumers' purchasing the more fuel-efficient cars in each size class, and 3) consumers purchasing smaller cars. Depending on market demand, success of technical developments and auto manufacturers' financial positions and capital stock, CAFE standards could be met through various mixes of the three (see table 8). Consequently, without special provisions it probably is impossible to establish conventional CAFE standards which simultaneously: 1) are effective (i.e., increase new-car fuel efficiency above what market forces would dictate), and 2) do not promote the sales of small imported cars. Separate fuel-efficiency standards for each automobile size or market class could significantly reduce the indirect promotion of small-car sales; however, this would greatly reduce automobile companies' flexibility in responding to the regulations.

The NSPP sets targets for synfuels production but the mandating of synfuels output has not been of central congressional interest. The major difficulty associated with developing synfuels stems from technical uncertainties which, in turn, affect the likely cost at which synfuels initially will be produced. in addition, contributions to oil import savings from synfuels would not be made incrementally (as with increasing automobile fuel efficiency) but rather depend on the proper functioning of large-scale facilities. As experience and knowledge is gained, it may become possible to establish realistically achievable production levels if the Government desires an assured level of synfuels supply.

Table 8.—Potential Average New-Car Fuel Efficiency in 1995

Car size class	Fuel efficiency of average model (mpg)[a]
Large	30-45
Medium	45-60
Small	60-75

Size mix of cars sold	Average new-car fuel efficiency (mpg)[a]
1961 size mix[b]	40-50
Moderate shift to small cars[c]	45-60
Large shift to small cars[d]	50-65

a All mpg figures rounded to nearest 5 mpg. Mpg refers to the composite consisting of 55 percent EPA city cycle and 45 percent EPA highway cycle,
b 1981 sales: 47 percent large cars, 48 percent medium-sized cars, and 5 percent small cars.
C 1995 sales: 20 percent large cars, 55 percent medium, 25 percent small.
d 1995 sales: 5 percent large cars, 45 percent medium, 50 percent small.

SOURCE: office of Technology Assessment.

One possible form of regulation would be to stipulate that a certain percentage of the output from domestic oil producers be synfuels. However, this provision would be unworkable for small oil producers, so it would have to be targeted at the larger oil companies. Similar problems arise with regulations aimed at refiners or retailers. Furthermore, because refining and retailing are considerably less profitable than gas and oil production, regulations aimed at the former might induce some of the companies that are vertically integrated to abandon refining rather than to incur the added costs and risks. For these reasons, it would probably be very difficult to administer mandates on synfuel content.

Other Effects

Environment, Health, and Safety

Both increased automobile fuel efficiency and synthetic fuels production have the potential for creating large-scale environmental, health, and safety hazards. A principal rationale for policy intervention is the general past failure of private markets to internalize these other effects in investment decisions and operating practices. Policies to protect the public have tended to take the form of regulations that govern known or anticipated impacts through performance standards or control specifications.

Apart from fuel efficiency, the auto industry is regulated in the areas of emissions and safety. Emissions standards require that each vehicle– and automobile safety standards require that each of certain vehicle parts-meet minimum performance standards. (By contrast, fuel-economy standards are for fleet averages.) There are proposals before Congress to delay, modify, or eliminate over 30 automotive-related environmental and safety regulations.[25]

A potential threat to the public from size and weight reduction of vehicles used to increase fuel efficiency is decreased automotive safety. The basic policy issue is whether the Government should act to help prevent future highway fatalities if consumer demand for safety does not result

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[25] See Gwenell Bass, "The U.S. Auto Industry: The Situation in the Eighties," CRS issue brief No. IB81054, Sept. 30, 1981.

in adequate safeguards. * Regulatory policy could, as examples, reconsider the passive restraint program (rulemaking for that program was terminated by NHTSA although a recent U.S. Court of Appeals ruling has reinstated the program, at least for the moment), mandate the use of safety belts, strengthen crashworthiness design standards, or maintain or tighten speed limits. Other types of programs could provide for stricter driver licensing standards and improved road maintenance and traffic control, support R&D, and provide for driver safety education. Another potential adverse effect is the air quality impact of a large increase in diesel-powered autos. Policy alternatives include more stringent particulate and NO_x emission regulations for diesel engines and Government assistance in diesel health effects research and emissions control development.

Potential environmental and worker-related problems associated with synthetic fuels development (e. g., contamination of drinking water, release of cancer-causing agents and other hazardous pollutants, highly visible plant upsets, obnoxious odors, and localized water availability conflicts) are substantial and have considerable potential for arousing strong public opposition. There are also elements of the present synfuels development strategy that appear to increase the potential for adverse impacts. These elements include the proposed siting of some synfuels demonstration plants close to heavily populated areas, research budget cuts at EPA and the proposed dismantling of DOE, the current policy to shift environmental management responsibilities to State and local agencies without a concomitant shifting of resources, and an industry environmental control program that appears reluctant to commit resources to currently unregulated pollutants and that may be overconfident about the performance of integrated control systems.**

"Manufacturers may not pursue safety for fear that the added cost will dampen market demand. In most cases safety has not been a strong selling point in automobiles in the past.

*"In apparent response to their confidence that adequate environmental control of synfuels plants will involve only "fine tuning" of existing control technologies, developers have passed up some opportunities to test out control systems on demonstration plants. For example, Exxon feeds the wastes from its Baytown, Tex., EDS plant into a neighboring refinery rather than developing and testing specific controls for the plant. In OTA's opinion this increases the risk of unforeseen problems at the first large-scale plants. Such problems appear quite possible given the differences between the conditions under which proposed control systems have been used previously (in chemical plants, refineries, etc.) and the expected conditions in synfuels plants.

Finally, the multiplicity of pollutants associated with synfuels production and the difficulty of detecting and evaluating some of the potential impacts (e.g., long-term cancer impacts from low-level exposures), coupled with the above factors, leads to a strong concern about the adequacy of future regulation of a synfuels industry.

Government actions targeted at the potential risks of synthetic fuels development may be an important factor in assuring that the risks are properly measured and in causing the private sector to account for these risks. A problem the Government faces, however, is that premature adoption of rigid standards could ultimately act to stifle innovation or force suboptimal environmental decisions. Also, the capital-intensive nature of the industry leaves it vulnerable to delays caused by shifts in environmental requirements or standards that ultimately prove unattainable.

The existence of these problems places a premium on an intensive research program and a round of demonstration plants, that include full environmental control systems, to avoid surprises and provide timely information for intelligent regulation. Also, the impact of an environmental surprise might be minimized by choosing isolated sites and requiring particularly strict controls for the first round of plants, thus minimizing the actual impact suffered from excessive discharges or other problems.

The vulnerability of synfuels plants to scheduling delays has also generated pressures on Congress and State legislatures to streamline environmental permitting for energy facilities. Although it is too early to assess recent streamlining efforts at both the Federal and State levels, considerable improvement appears possible **without** a **full-scale Energy Mobilization Board.**[26] In most cases, regulatory delays are important only to the extent they delay construction starts or require changes in plant design; otherwise, all necessary permits are likely to be obtained before significant construction investment has been made. Delays after construction has started could, however, be costly. A 3-year delay, for example,

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[26]Congressional **Research Service,** ''Synfuels **From Coal and the National** Synfuels **Production Program: Technical, Environmental, and Economic Aspects. "**

could increase synfuels product costs by 20 percent or more. In addition, the risk that retrofitting may be required will remain until synfuel processes have been proven and both emissions and products extensively tested. Formulating regulatory policy entails an assessment of the full range of regulatory costs to industry versus the possible costs arising in the absence of policy. At present these complex tradeoffs are often determined in a lengthy, case-by-case process based on judicial interpretations.

policy alternatives to regulation include effluent charges and pollution vouchers. Although such mechanisms have a strong theoretical basis, there is a general lack of practical experience in using them. Also, the toxic pollutants of most concern in synfuels production cannot safely be traded off among sources the way pollutants such as SO_2 and NO_x can be.

There are two additional levels for policy involvement. First, Congress could decide to increase the environmental capabilities of responsible regulatory agencies. One specific option is to target resources for specific State and local environmental agencies, as was done under the Clean Air Act in the early 1970's. As a part of this option, Congress may also wish to investigate the effects of the programmatic changes and budget reductions for synfuels environmental research and control system development at EPA and DOE.

Secondly, environmental concerns could be integrated directly into financial support decisions —i.e., of SFC. Although some would claim that this latter option is redundant given current environmental legislation, there are nevertheless many concerns (e.g., siting) which are not well-addressed by existing laws. In addition, the protection of SFC investments would be well-served by an ability to influence environmental planning. SFC has not yet moved aggressively to build a technical capability for the environmental assessment of projects it will support.

The availability of water resources may pose special problems for policy because of the present controversies surrounding the allocation and use of increasingly scarce supplies.[27] How conflicts are resolved in areas where users presently or could potentially compete for water will have important implications for the distribution of costs and benefits to all water users, especially since the costs of procuring water are likely to be small (in comparison with other costs) for the synfuels industry. Present water policies and planning mechanisms are fragmented and generally inadequate to assess water availability and plan for future water needs on a consistent, comprehensive, and continuous basis. Because of the magnitude, diversity, and nationwide distribution of water resource problems and because the outcome of water-resource allocation conflicts will have local, State, regional, and National impacts, the Federal Government has an important role to play in improving water resource management practices in cooperation with the States. Major policy issues include the resolution of uncertainties surrounding water rights and future water needs and the definition of responsibilities, objectives, and priorities for water planning and allocation. Legislation pending before Congress (e.g., S.1095 and H.R. 3432, which both call for the dismantling of the U.S. Water Resources Council) seeks to redefine the respective responsibilities of Federal and State Governments and to clarify the role of regional and local interests in managing water resources.

Social Adjustment Assistance

Increasing automobile fuel efficiency and developing a synfuels industry will result in social costs and benefits which are side effects, i.e., effects that are external to the transactions made between consumers and producers. The movement of capital and labor as a result of industrial change (i.e., restructuring, contraction, or growth) will have implications not only for the character of the labor market but also, consequently, for lifestyles and standards of living.

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[27]For further discussion of these issues see *An Assessment of Oil Shale Technologies,* OTA-M-118 (Washington, D. C,: U.S. Congress, Office of Technology Assessment, June 1980); and *A Technology Assessment of Coal Slurry Pipelines,* OTA-E-60 (Washington, D. C., U.S. Congress, Office of Technology Assessment, March 1978).

in **the** auto industry, the major social effects are related to job losses resulting from structural adjustment. In the synfuels industry, the major social externalities are related to new employment and result from large, rapid and fluctuating population growth in some areas where the industry may locate. Government policy may be important both for easing those social adjustments that the market does not address and for ensuring that associated costs do not fall disproportionately on particular groups. Social-adjustment assistance in this country has generally been limited in the past to sectors affected by international trade and to several programs focusing on regional adjustment.

Labor market dislocations are of primary importance to the Nation because of the penetration, numbers, and dispersion of auto-related jobs throughout the economy as well as the geographic concentration of auto production jobs. Restructuring of the industry for improved international competitiveness, productivity, and fuel efficiency is resulting in what is likely to be a long-term decline in auto-related employment.

The problem of unemployment in the auto industry could be addressed by policy measures that seek to ease the adjustment of firms, workers, and communities to changing economic conditions. Policy options include, as examples: relocation assistance, support of retraining programs and training institutions, local content provisions, manpower training vouchers for targeted individuals, plant-closing restrictions, tax incentives to other industries (or regions) to attract displaced workers, and community aid programs (e. g., to diversify local economies).

Some assistance has been available under the Trade Act of 1974 provisions and through Housing and Urban Development, the Economic Development Administration, and other Government agency programs. These programs have generally been limited in scope and funding and have generally required evidence of economic distress (i.e., they are not preemptive). They are also candidates for curtailment under proposed Federal budget cuts. Note that because employment displacement depends in part on labor costs, automobile-related employment levels will

also vary with the degree to which autoworkers accept changes in compensation and work rules, behavior which is not generally subject to direct Federal policy initiatives.

Major social side effects arise from synfuels development because the communities which absorb the large, rapid population increases (a portion of which is only temporary) are vulnerable to institutional and social disruptions. These externalities could constrain synfuels development by generating public opposition to synfuels and by adversely affecting worker productivity. The principal policy issues relate to who will bear the costs of managing and mitigating these disruptions and how up-front capital can be made available to finance necessary public facilities and services. Those who view social impacts as the price of regional development emphasize the responsibilities of State and local governments working with private developers. Those who associate local impacts primarily with the pursuit of national energy objectives call for a continued and expanded Federal role.

There are also many questions of equity that arise in allocating resources among different areas, because of the large variations in the magnitude and character of adverse impacts and the resources available to cope with these impacts. An acceptable assistance program must deal with the problem that some of the shortages of impact-mitigation resources are caused by limitations on planning and borrowing powers imposed by local and State governments themselves.

Current policies to deal with the social impacts of energy development are unable to address consistently and comprehensively the cumulative impacts arising from the large-scale, rapid-growth situations that characterize synfuels development. Government policies could be directed at either energy development generally or synfuels production specifically, and could provide, as examples: financial aid, technical assistance, growth management planning assistance, regulation (e.g., with respect to siting, phasing, pacing, monitoring), lending and borrowing assistance, or taxing provisions. The various forms of technical and financial assistance for growth management are

examined in detail in previous OTA studies.[28][29][30][31] All relevant Federal programs have been targeted for substantial budget reductions, or elimination, in fiscal year 1982 under proposals submitted to Congress by the present administration.[32]

The development of a synfuels plant will lead to the creation of new jobs in construction and

engineering. Technically qualified personnel should be available for most of these jobs. However, a shortage of experienced chemical process engineers and project managers could arise, causing costly mistakes and production delays. The overall number of chemical process engineers, for example, would have to increase by about one-third by the mid to late 1980's to accommodate an optimistic level of synfuels plant construction.

The Federal Government could encourage the education of engineers by providing financial support for facilities, equipment, retraining programs, scholarships, and the hiring and retraining of faculty. Training in skills needed for complex project management could similarly be stimulated. The auto industry would also benefit from programs to train engineers if the industry pursued extensive development efforts domestically.

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[28]*An Assessment of Oil Shale Technologies,* Op. cit.

[29]*The Direct Use of Coal,* OTA-E-86 (Washington, D. C.: U.S. Congress, Office of Technology Assessment, April 1979).

[30]*Management of Fuel and Nonfuel Minerals in Federal Land,* OTA-M-88 (Washington, D. C.: U.S. Congress, Office of Technology Assessment, April 1979).

[31]A₍ₙ₎*Assessment of Development and production Potential of Federal Coal Leases,* OTA-M-150 (Washington, D. C., U.S. Congress, Office of Technology Assessment, December 1981).

[32]Congressional Research Service, "Energy Impact Assistance Legislation, " issue brief No. 1679022, Sept. 9, 1981.

CONCLUSIONS

Both increasing automobile fuel efficiency and synfuels production have economic and noneconomic risks and external costs. The decision to pursue either, or both, alternatives–as well as to pursue the third major technical alternative of fuel switching and conservation in stationary uses of petroleum—depends on the desired rate and level of oil import displacement and what the Nation is prepared to spend to achieve its oil-displacement goals.

The availability and cost of capital are especially important for the automobile and synfuels industries, since they are both capital-intensive. General economic conditions affect consumer confidence and purchasing power. Among the policies mentioned in this chapter are general tax policies and special taxing provisions which would encourage capital formation and stimulate industrial innovation economywide.

The rate at which automobile fuel efficiency can be increased and a synfuels industry developed are also affected by factors that are specific to each alternative. Contributions to oil-import displacement from increased automobile fuel efficiency depend critically on consumer demand for fuel-efficient cars. Government actions to stim-

ulate demand are a direct way to help ensure that fuel-efficient cars are bought and, in turn, that they will be produced. Demand-oriented measures that appear promising and that deserve further analysis include registration, purchase, and fuel taxes and purchase subsidies. Supply incentives, depending on their nature, could help manufacturers pay for the investments necessary to increase fuel efficiency, especially if there is an absence of strong demand for either cars in general or fuel-efficient cars in particular. In the case of weak demand for efficiency, increasing CAFE standards beyond the 1985 level may help to ensure continued oil import displacement. However, the increased cost of the efficiency increases could reduce new-car sales and thereby reduce the potential savings. In general, a combination of demand and supply incentives would be the most effective means of promoting more efficient fuel use in automobiles. This would contrast with past policy, which has been aimed largely at producers.

The success of synfuels development in displacing oil imports hinges on the resolution of major technical uncertainties associated with as yet un-

proven processes. private investments are likely to be accelerated once processes are demonstrated in commercial-scale units—provided the processes are economically competitive sources of fuels. The high costs and other risks associated with demonstration projects are likely to necessitate Government support if synfuels production is to become a significant fuel source by the end of the century.

Other policy considerations for displacing oil imports are applicable generally to planning in a world of uncertainty. First, flexible and nonspecific policy interventions provide both public and corporate decision makers with the maximum opportunities to adjust internally to changing economic and technical circumstances. Secondly, periodic reviews and adjustments can help prevent prematurely locking the Nation into technical choices that discourage a continuing search for better methods, although too much flexibility can lead to ad hoc programs.

A long-term, stable policy commitment to oil import displacement, and to alternatives for displacing imports, is essential in order to send clear signals about Government intentions and promote mutual confidence in any public-private relationship. In the past, the Government has sometimes sent conflicting signals. For example, concurrent Government programs were in place, on the one hand, to encourage automobile fuel economy with CAFE standards and, on the other hand, to discourage fuel conservation with price controls on oil which helped to keep the price of gasoline low. *

Increased automobile **fuel** economy and synfuels production contribute in different ways to the Nation's energy security. The advantages of automobile fuel efficiency include the following: 1) through conservation, it directly eliminates the **need** for oil imports in the Nation's highest petroleum-consuming sector; 2) after large numbers of fuel-efficient vehicles have been sold, the **fuel**

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*U.S. policies in the 1970's also implicitly encouraged oil use for stationary purposes (e.g., Federal curtailment policy for natural gas).

savings does not depend on the operation of a few large plants, and there will continue to be fuel savings even if particular vehicles perform below standards; 3) it does not result in a net reduction of natural energy resources and thus preserves options for future generations; and 4) although there are long leadtimes for commercializing new products in the auto industry, savings are already occurring as technologies are diffusing into the consumer market. However, if market and/or Government pressures for increased automobile fuel efficiency damage the U.S. auto industry, there will be repercussions throughout the economy.

The principal national security advantage of synfuels production is that it may provide long-term strategic insurance against sustained shortfalls. Rapid and successful deployment could conceivably serve to reduce the rate at which oil import prices increase and thus help to reduce inflation. The vulnerability of the synfuels alternative is related to the complexity of technical controls, the high risks and costs of failure, potentially hazardous environmental side effects, institutional barriers to deployment, and, in some cases, the geographic concentration of facilities.

Because increasing auto fuel efficiency and synfuels development are both capital-intensive, each will incur major economic penalties if facilities function below capacity. However, because the "normal" rate of capital turnover is likely to be lower in the synfuels than the auto industry, synfuels production will be more limited in adapting to changing demands.

Developing a long-term, coordinated, and comprehensive energy policy will be an incremental process. A prime objective is to choose a least cost mix of options for reducing oil imports. Because investment costs (per barrel per day of oil saved or replaced) for the various options considered in this report for the 1990's are highly uncertain, yet appear to be comparable in magnitude, the judgment of relative costs will depend largely on value assessments of the various externalties of pursuing each option.

APPENDIX 3A.–POLICY OPTIONS TO REDUCE STATIONARY OIL USE

Conservation

1. **Tax credits for investments in conservation:**
   - Ž **Current 15-percent credit for investments by homeowners–single-family and 4-unit or less multifamily.**
   - ● **10-percent tax credit** for energy efficiency or renewable resource investments by industry.
2. Residential Conservation Service:
   - ● Utility audit service for homeowners.
   - ● Proposed extension to include apartment and commercial buildings.
3. Subsidized loans to homeowners to finance conservation investments:
   - ● Currently the purpose of the Solar and Conservation Bank.
   - ● Private savings and loan institutions also offer below-market loans for conservation in some cases.
4. Targeted tax credits (20 percent) for investments in energy efficiency by industry:
   - ● Currently proposed in legislation now before Congress.
   - ● Tax credit in addition to current credits.
5. State public utility commission actions to encourage conservation efforts by utilities:
   - ● Allowance of conservation investments in the rate base of utilities (proposal).
   - ● Permission to sell saved energy to private investors (proposals).
   - ● Allowing utilities to set up separate companies to **provide conservation services—now occurs in some cases,**
6. **Legislating standards and/or information:**
   - ● Appliance efficiency standards–labeling of appliances.
   - ● Building standards–currently prescriptive standards through the minimum property standards of the Department of Housing and Urban Development.
   - ● Building energy performance standards are legislated but currently not enforced.
   - ● Efficiency standards for industrial electric motors were proposed but never enacted.

Fuel Conversion

1. Prohibition on oil use by utility boilers and large industrial boilers:
   - ● Principal focus of the Fuel Use Act.
   - ● Goal to eliminate use of oil by 1990.
2. Financial assistance for utilities to convert from oil to coal:
   - Ž State commissions have allowed New England Electric Co. to secure a "loan" from their customers to pay for an oil-to-coal conversion.
   - ● Federal legislation proposed to provide loan guarantees for these conversions was never passed and is not likely to be pursued now.
3. Legislation to remove regulatory restrictions on use of natural gas by industry:
   - ● Currently part of several proposals to encourage conversion to natural gas.
   - • Current regulations (Federal and State) either prohibit or discourage natural-gas use for many applications that now use fuel oil.
4. Environmental regulations affecting coal use in industry:
   - ● Lowering of emission standards for applications below a certain size.
   - • Financial assistance to help install control technologies.

General

1. R&D to increase efficiency of end-use technologies:
   - ● Promotes general conservation.
   - ● Can also be directed at developing efficient electric energy using technologies to make the economics of switching to electricity attractive.
2. Tax on oil–either on imports or on specific products such as fuel oil for boilers or space heating:
3. Economic incentives for development of unconventional natural gas:
   - ● Currently unconventional natural gas is completely deregulated.
   - ● Tax credits to encourage development of unconventional gas (this is currently not available).

APPENDIX 3B.–ADDITIONAL CRS REFERENCES

The Congressional Research Service has recently published many reports on various aspects of energy policy to which the reader is referred. These reports include the following:

1. Rothberg, Paul, 'Synthetic Fuels Corporation and National Synfuels Policy, " CRS issue brief No. 1681139, Oct. 13, 1981.

2. Chahill, Kenneth, "Low-Income Energy Assistance Reauthorization: Proposals and Issues, " CRS mini brief No. MB81227, Aug. 26, 1981.

3. Abbasi, Susan R., "Energy Policy: New Directions Indicated by the Reagan Administration's Budget Proposals, " CRS mini brief No. MB81222, June 29, 1981.

4. Parker, Larry, Bamberger, Robert L., and Behrens, Carl, "Energy and the 97th Congress: Overview," CRS issue brief No. 1681112, Sept. 15, 1981.

5. Rothberg, Paul, "Synthetic Fuels Corporation, Policy and Technology," CRS mini-brief No. MB79245, July 13, 1979, updated Apr. 20, 1981.

Chapter 4

Issues and Findings

Contents

Issues and Findings

INTRODUCTION

This chapter is a summary and comparison of major results from the analyses discussed later in the report. It also contains additional analyses where needed to put the results in perspective.

It begins with a discussion of the true cost of imported oil. Increased automobile fuel efficiency, synfuels, and conservation and fuel switching in stationary petroleum uses are then compared according to the speed with which they can act to reduce oil imports and their respective investment costs. Increased auto fuel efficiency and synfuels are compared according to their environmental, social, and economic impacts. Estimated consumer costs for increased automobile fuel efficiency and synfuels are also given in separate boxes, but the uncertainties are too large for any meaningful comparison. In addition, there is a box discussing the uncertainties in total consumer costs for each of the oil displacement options.

Following the comparisons, several issues related specifically to increased automobile fuel efficiency or to synfuels are covered. For automobiles, the issues include the effects of incentives for increased fuel efficiency on the evolution and health of the U.S. auto industry, the possibilities for a highly fuel-efficient car, the safety of small cars, current demand for fuel efficiency i n cars, and the prospects for electric vehicles. For synfuels, probable environmental dangers, water constraints, and compatibility of synfuels with existing end uses are considered.

Each separate entry in this chapter is designed to stand alone and generally does not build on other material in the chapter. The chapter is not designed to be read from beginning to end; rather, each reader can turn directly to those comparisons and issues of interest without loss of context or regard for the way the entries are ordered.

WHAT DO OIL IMPORTS COST?

The private U.S. consumer pays the going market price for imported oil, but that is not its only economic cost. In the last decade, the Nation has been forced to pay a substantial additional "premium" because of its strategic dependence on a small number of foreign oil producers. During especially unstable periods, such as the 1973-74 Middle East War and the 1978-79 Iranian Revolution, this import premium payment is highly visible and, when measured in terms of the incremental cost for that segment of demand which clearly exceeds available supplies, it can greatly exceed the actual market price.

It is reasonable to attribute an exceptional premium payment to oil, and not to other imported goods and services, because uninterrupted oil supplies are critical to economic stability (i.e., few substitutes exist at least in the short run) and because the United States has become the prominent importer on the world scene and has as-

sumed major responsibility for protecting world oil trade. No other import constitutes such a vital economic resource that must flow in such a large continuous stream around the world. Although the third quarter of 1981 has witnessed falling oil prices and a modest supply surplus, future shortage risks remain plausible because of the expected longrun depletion of world oil reserves and because of unresolved and potential international conflicts.

The existence of a national premium payment for oil imports can be explained in terms of three economic relationships:

1. the dependence of international price on the quantity of U.S. imports;
2. the loss of U.S. jobs and gross national product (GNP) caused by oil payments abroad and the associated depreciation of the dollar; and

3. the **budgetary cost of military outlays and foreign** military **assistance related to assuring the security** of oil imports. These are described below.

Dependence of Price on Quantity Imported

Market price is a good measure of real or total cost when markets are competitive and in a state of stable equilibrium. Neither situation is characteristic of international oil markets, which are dominated by a small number of sellers and buyers in an unstable marriage of short-term convenience. Despite the complexity and unpredictability of this relationship, it seems reasonably clear that raising U.S. oil imports drives price upward and vice versa, simply because any movement by such a prominent importer appears to the rest of the world as a shift in the world demand curve. This positive relationship between quantity imported and price means that the cost of incremental U.S. consumption exceeds current price because the increment makes all future consumption more expensive. Conversely, decrements in U.S. consumption save more money than the marginal reduction in purchases.

Eventually, oil markets may anticipate this price/quantity relationship, but market adjustments may not be smooth. Shocks can be expected, leading to domestic inflation and recession, because international relationships between exporters and importers have become politicized and because significant reductions in oil consumption are difficult to achieve over periods of up to several years due to the long lifetimes of energy-related capital stock and the long leadtime for alternative domestic fuels.

Loss of U.S. Jobs and GNP Caused by Rising Oil Payments and by Potential Supply Interruptions

Oil imports accounted for 26 percent of U.S. payments for imports in 1979, which is about twice the level of the second largest item. Consequently, compared with equivalent rates of growth or decline for other imports, changes over time in oil payments have a relatively large impact on the U.S. balance of trade, and, hence, a relatively large impact on the exchange value of the dollar.

In periods when the dollar is relatively strong, as it has been recently (second half of 1981), it is due in part to declining oil payments. In periods when the dollar is weak, as it was during most of the 1970's and especially after 1975 because of large deficits in merchandise trade, growing oil payments increase selling pressure on the dollar, lowering its foreign exchange value. While this makes U.S. exports more attractive to foreign buyers, export sales may not increase elastically because of stagnant world economy or failure of U.S. goods to meet quality standards. Therefore, market adjustments, including both higher prices and undoubtedly reduced purchases, are forced on U.S. importers.

Furthermore, the declining value of the dollar has relatively little effect on oil imports, again due to the long lifetimes of capital related to oil consumption. Barring economic recession, oil consumption significantly declines only with the slow replacement of capital. Thus, even though rising oil imports or sharply rising oil import prices may be clearly responsible for dollar depreciation, oil consumption may not bear the brunt of the resulting short-term adjustment.

Overall, adjustments in the U.S. balance of payments also affect domestic economic activity. A sharply rising oil import price directly increases domestic inflation while at the same time larger foreign payments can lower total demand for domestic goods and services if, as is likely in the short run, oil exporters do not spend their larger receipts in the United States. This combination of rising inflation and declining total demand puts the Federal Government in a difficult position because corrective policies are contradictory. If control of inflation is the primary objective, sharp oil price increases may force the Government to brake the growth momentum of the national economy or exaggerate downward cycles in order to limit propagation of inflationary pressures.

In addition to oil price shocks, potential supply interruptions of oil imports present the clearest, most direct threat to national economic activity. As discussed above, few good substitutes exist

for oil in the short run, so that reduced flow results in lost production and unemployment as *soon* as stockpiles can no longer make up for the deficit.

The potential premium payment, implied by both unstable oil import prices and supply interruptions, can be illustrated in terms of the 1973-74 shock. In 1974 and again in 1975, real GNP declined by more than a percentage point after having grown at a rate of 5 percent in 1973 and 4 percent in 1972. Although cause and effect in macroeconomics is highly speculative, the losses in 1974 and 1975 are widely believed to have been due in part to the disruption of oil supplies and the associated quadrupling of imported oil prices. If, in fact, real GNP growth had been reduced by just one percentage point by oil-related events, it would have meant a loss of about $15 billion in U.S. production ($1.5 trillion GNP in 1975), which amounts to $6.80 per barrel **(bbl)** for the 2.2 billion bbl imported that year. The price of oil at that time was about $11.

Military Outlays and Foreign Policy Directions Forced by Oil Import Dependence

Military and foreign policy are predicated on many national objectives, but apparently one very important consideration for the United States is protection of oil supply lines. The cost of such protection cannot be ascertained directly, but current debate over defense budget priorities indicates that the United States intends to develop weapons systems and train personnel in order to be able to fight a war in the Middle East, if necessary.

If 10 percent of estimated 1982 defense outlays were justified to meet military threats to Middle East oil supplies, it amounts to about $18 billion or about **$9/bbl** for the 2 billion bbl of oil imported (net of exports) in 1981.

Conclusion

The complexity and unpredictability of world oil markets and world oil politics make it difficult to predict the oil import premium over time. * In OTA's judgment, the possible future import premium could range up to $50/bbl. It could be negligible if world demand continues its sharp downward trend and if major new discoveries are made outside the Middle East, but could be much larger than the current price of oil if hostilities break out which cut off most supplies from the Middle East.

A technical analysis must stop short of greater certainty except to indicate that a significant reduction of imports would drive the premium down by reducing the visibility of the United States in world oil markets and by reducing U.S. dependence on supplies from politically unstable countries. In other words, the premium payment for the last barrel of imports is much higher than for the first, and it is the last barrel which would be displaced by domestic synfuels or by higher fuel efficiency in automobiles.

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*A number of estimates for both components of the oil import premium are available. For the most detailed discussion of related economic issues and documentation of results from current economic models, see *World Oil,* **Energy Modeling Forum, Stanford** University, **Stanford,** Calif.,ch. **5 (forthcoming).**

HOW QUICKLY CAN OIL IMPORTS BE REDUCED?

Options for reducing U.S. oil consumption are considered in detail later in the report. Here, the results of those analyses are summarized and the relative contributions that the various options can make to reducing imports over the next two decades are considered.

Table 9 shows the estimated level of imports in the absence of synthetic fuels and automobile fuel-efficiency increases beyond a 1985 level of 30 mpg. This base case also assumes: 1) the Energy Information Administration's (EIA) high oil price future to 1990 for the consumption of oil

**Table 9.-Minimum Oil Imports
for Base Case (MM B/DOE)**

	1980	1985	1990	1995	2000
Stationary demand[a](no additional measures past 1990)	8.1	7.3	6.4	6.4	6.4
Transportation demand (other than automobiles	4.5	4.7	5..0	5.4	5.7
Automobiles (with 1985 new-car average of 30 mpg, no change thereafter)	4.3	3.6	3.0	2.7	2.7
Sum of demand	16.9	15.6	14.4	14.5	14.8
Domestic production	10.2	8.6	7.6	7.1	7.0
Imports.	6.7	7.0	6.8	7.4	7.8

[a]Includes all nonfuel oil uses such as asphalt, petrochemical feedstock, liquefied petroleum gas, etc., which are projected by the Energy Information Administration to total 3.8 MMB/D by 1990,
[b]Oil plus natural gas liquids.

SOURCE: Office of Technology Assessment,

for stationary uses;[1] 2) the transportation petroleum demand (other than for passenger cars) explained in chapter 5; 3) fuel oil demand by stationary uses is held constant after 1990; and 4) the maximum domestic oil production projected by OTA.[2] For 1995 and 2000, the trends of the 1980's for stationary uses of petroleum other than fuel oil have been extrapolated, while holding fuel oil consumption constant at the projected 1990 level. The assumption of constant fuel oil demand for the 1990's was chosen as the base case to help illustrate the importance of eliminating this demand relative to other options for reducing oil imports in the 1990's.

It should be emphasized that a considerable reduction in oil consumption through increased efficiency and fuel switching in the 1980's is already built into the base case. in particular, achieving an average new-car fuel efficiency of 30 mpg by 1985 saves about 0.8 million barrels per day oil equivalent (MMB/DOE) by 1990, relative to 1980 demand;* and conservation and fuel switching in the EIA high oil price scenario reduce oil consumption by 1.7 million barrels per day

[1] Energy Information Administration, U.S. Department of Energy.
[2] *World Petroleum Availability: 1980-2000— Technical Memorandum, OTA-TM-E-5* (Washington, D. C.: U.S. Congress, Office of Technology Assessment, October 1980).
*The fuel saved in cars is 0.9 million barrels per day (MMB/D), but the assumed increase in transportation needs raises consumption in other types of transportation by 0.1 MMB/D.

(MMB/D) in stationary uses by 1990. However, domestic oil production is likely to drop by at least 2.6 MMB/D during this same time period,[3] thereby nullifying any reduction in oil imports from these measures alone.

Table 10 shows the various reductions in oil consumption that may be achieved beyond the base case. These include contributions from further conservation and fuel switching in stationary uses, increased automobile fuel efficiency beyond a 1985 level of **30** mpg, electric vehicles (EVs), and synfuels. Each of the areas where additional oil savings are possible is discussed below.

By 1990, stationary demand for residual and distillate *fuel* oil is 2.6 MMB/D in the base case. * As explained in chapter 7, a combination of cost-effective conservation measures and switching to natural gas and electricity can eliminate this stationary fuel oil demand without a need to increase gas production or electric generating capacity. How much of this potential actually is reached will depend on such things as individual decisions about conservation investments and

[3] *World Petroleum Availability: 1980-Technical Memorandum,* op. cit.
*The remainder of the 6.4 MM B/D of stationary oil use includes asphalt, petrochemical feedstocks, liquefied petroleum gas, and refinery still gas.

**Table 10.—Contributions to the Reduction of Oil
Imports Beyond the Base Case (MMB/DOE)**

	1980	1985	1990	1995	2000
Conservation and switching in stationary applications	0	0	0	0.8[a]-1.3	I.5[a]-2.6
Increased automobile fuel efficiency beyond 1985 average of 30 mpg	0	0-0.1	0.1-0.5	0.3-1.0	0.6-1.3
(Average new-car efficiency, mpg[b])	(23)	(30-37)	(36-49)	(40-63)	(45-79)
Electric vehicles . . .	0	0	0	0	0-0.1
Synthetic transportation fuels:					
Fossil	0	0-0.1	0.3-0.7	0.7-1,9	1.3-4.5
Biomass	0	(c)	0-0.3	0-0,6	0,1-1.0
Total	0	0-0.20	.4-1.5	1.8-4.8	3.5-9.5

[a]Energy Information Administration forecast.
[b]55 percent EPA city/45 percent EPA highway test cycles.
[c]Less than 0.05 MMB/D.

SOURCE: Office of Technology Assessment.

availability of transmission and distribution systems. The most recent projection of EIA provides a reasonable lower bound on the reduction in fuel oil that can be achieved during the 1990's.

The range of potential savings from increased automobile fuel efficiency corresponds to the low and high estimates derived in chapter **5** and different assumptions about relative future demand for small-, medium-, and large-sized cars, i.e., 1) no shift to smaller cars and pessimistic assumptions about efficiency increases from automotive technologies, and 2) a substantial shift to smaller cars and optimistic assumptions about the technologies. By **2010,** automobiles containing the average technology of 2000 would have replaced most cars on the road and the savings, relative to the base case, would be 0.8 to 1.7 MMB/D (2.3 to 3.2 MMB/D relative to 1980 demand).

It should be emphasized that average new-car fuel efficiencies shown in table 10 do not represent a technical limit to what can be achieved. In any given year, cars with higher (and lower) mileages than those shown would be produced and sold. * Rather, the mileage ranges correspond to what OTA considers to be feasible through a variety of technological improvements.

If a very strong demand for fuel-efficient cars develops, e.g., as the result of continued large oil price increases, consumers may be willing to accept poorer performance or pay the added cost in order to achieve higher fuel efficiency. In this case, the estimated average fuel efficiency shown for 2000 in table 10 could be achieved by the mid- 1990's.

The contribution from EVs was calculated by assuming that O to 5 percent of passenger automobiles would be electric by 2000, growing linearly from O percent at 1985, The savings from EVs is relatively small, however, because of the relatively low consumption of petroleum by automobiles (1.3 to 2.1 MMB/DOE in 2000) and the

fact that EVs would be a substitute for the most fuel-efficient cars.

The final category in table 10, synthetic fuels, must be considered carefully to ensure that only the synthetic fuels production that displaces oil is included and technical difficulties are accounted for. To derive the low estimate of synfuels contributions, it is assumed that by the time synthetic fuels become available, the only remaining stationary uses of petroleum are for chemical feedstocks, asphalt, petroleum coke, still gas, and liquefied petroleum gas (LPG). Since these products cannot now be economically converted to transportation fuels, the low estimate in table 10 assumes that their replacement by synthetic fuels (synthetic gas) would not result in additional transportation fuels. * In addition, poor performance of the first round of synfuel plants is assumed, limiting production until the early to mid-1 990's. As a consequence of this, the low synfuels production scenario from chapter 6 is used in the table 10 low estimate.

A more optimistic scenario is possible if it is assumed that market or other forces strongly favor the production of transportation fuels over synthetic fuel gases and that half of the synthetic gas* * plants projected in chapter 6 actually are built to produce synthetic transportation fuels. With these assumptions and the high scenarios presented in chapter 6, one arrives at the upper estimate for oil displacement by synfuels shown in table 10. The high estimate, however, represents a vigorous dedication to synfuels production and what might be termed near "war mobilization" development of the industry.

The range of oil savings from each of these sources is shown in figure 4, alongside the import levels calculated in the base case. As can be seen, under the most favorable circumstances it is technically possible to eliminate oil imports by 2000. However, if domestic oil production[5] is below that shown in table 9 and if only the low estimates of table 10—or even only the low esti-

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*For **example, u p until January 1981, the 1981 model new-car fuel efficiency of cars sold averaged slightly less than 25 mpg, but if the** *most* **fuel-efficient cars in each size class had been bought, the average would have been about 33 mpg.**[4]

[4]**Derived from data in J. A. Foster, J. D. Murrell, and S. L. Loos, "Light Duty Automotive Fuel Economy . . . Trends Through 1981 ," U.S. Environmental Protection Agency, SAE paper No. 810386, February 1981,**

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*LPG can, however, be used directly in appropriately modified automobiles.

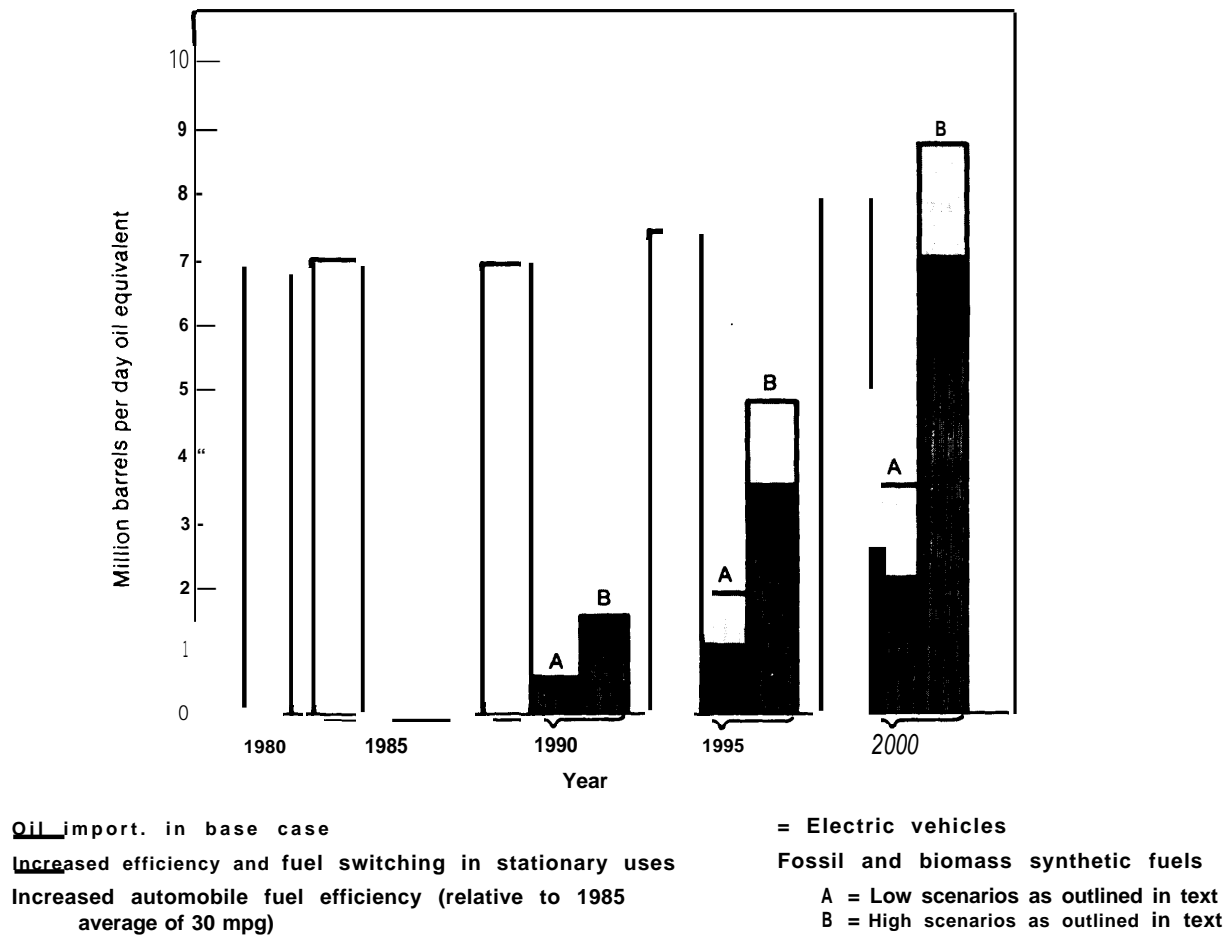**Excluding biogas from manure, which would be used principally on the farms where it is produced.

[5]*World Petroleum Availability: 1980-2000- Technical Memorandum,* op. cit.
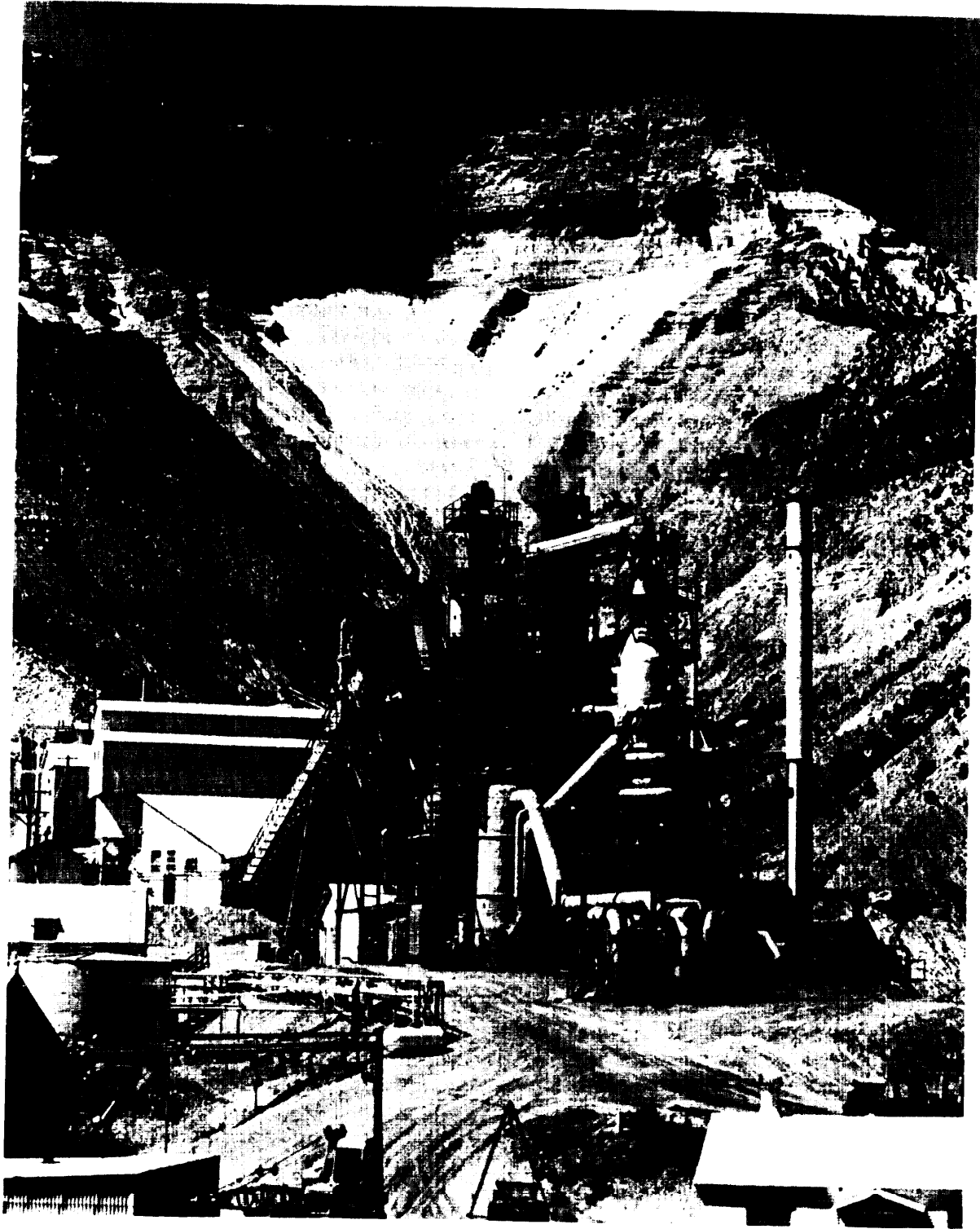
The Paraho Semiworks Oil Shale Unit at Anvil Points, Colo.

Figure 4.—Comparison of Base Case Oil Imports and Potential Reductions in These Imports

<u>Oil import. in base case</u>

<u>Incre</u>ased efficiency and fuel switching in stationary uses

Increased automobile fuel efficiency (relative to 1985 average of 30 mpg)

= **Electric vehicles**

Fossil and biomass synthetic fuels

A = **Low scenarios as outlined in text**
B = **High scenarios as outlined in text**

SOURCE Office of Technology Assessment.

mate for synfuels—are reached, then it is quite unlikely that oil imports can be eliminated before sometime well into the first decade of the 21st century.

Although the large number of noteworthy uncertainties make an exact determination of the course of oil imports impossible, several conclusions can be drawn.

First, increased efficiency and fuel switching in buildings and industry are extremely important for the reduction of oil consumption. Although much of the potential in this area will be achieved through market forces by **2000** under the high oil price scenario of EIA, implementing the necessary changes at an earlier date could significantly reduce oil imports before **2000.** For example,

fully implementing the potential for reducing stationary uses of fuel oil by 1990 would save about 15 billion bbl of oil imports or $600 billion (at an average of $40/bbl) for the imports during the period 1981-2000.

Second, synthetic fuels development has approximately the same importance as the conservation and fuel switching options but its contribution to reduced imports will not be as large until at least the late 1990's. Further, if a large part of the synfuels is used as a substitute for increased efficiency and for conventional fuel switching in stationary uses or as a substitute for petroleum products not readily converted to transportation fuels, elimination of oil imports is likely to be delayed.

Third, increases in automobile fuel efficiency beyond a 1985 average of 30 mpg could reduce automobile fuel consumption 20 to sO percent (0.6 to 1.3 MMB/D) by 2000 below the fuel consumption of a 30-mpg fleet. in addition, because fuel efficiency increases in automobiles (to and beyond **30** mpg) could reduce the automobile's share of transportation fuel needs from so percent (in 1980) to 20 to 25 percent (in 2000), it is likely that efficiency increases in various non-automobile transportation uses beyond those assumed in the base case could also make significant contributions to reducing transportation fuel

needs. This option has not been analyzed by OTA.

In summary, it probably will be necessary to implement fully all of the options for reducing oil consumption if one wants to eliminate net oil imports before the first decade of the next century. This will require full implementation of charges needed for increased efficiency in all uses of oil and fuel switching in stationary uses, as well as directing synfuels production to transportation fuels.

WHAT ARE THE INVESTMENT COSTS FOR REDUCING U.S. OIL CONSUMPTION?

Introduction

investment costs are an important consideration when comparing alternatives for reducing U.S. oil consumption. OTA's analysis indicates that synfuels production, increased fuel efficiency in automobiles, and conservation and fuel switching in stationary uses of oil all will require investments of the same order of magnitude for comparable reductions in oil. consumption in the **1990's;** whereas, synfuels production appears to require larger investments than the other alternatives for the 1980's. Uncertainties in the cost estimates as well as the fundamental differences in the nature of the investments are too large, however, to allow a choice between approaches on this basis alone.

In order to compare investment costs, they have been expressed as the investment needed to either produce or save 1 barrel per day oil equivalent* of petroleum products. This method was chosen in order to avoid problems that arise when comparing investments in projects with different lifetimes and for which future oil savings may be discounted at different rates.** In addition, from a national perspective the per unit in-

vestment cost is important in that it is the parameter used in the aggregate to make choices among competing investments. Conventional oil and gas exploration are considered first to provide a reference point. Following this, OTA's estimates for the investment costs for increased automobile fuel efficiency, EVs, synfuels, and increased efficiency and fuel switching in stationary uses are discussed briefly.

Conventional Oil and Gas Production

Two estimates of recent investment costs for conventional oil and gas exploration and development in the United States are shown in table 11. The data in this table were developed from estimates of the annual investments in oil, gas, and natural gas liquids exploration and development per barrel of increased proven reserves of these fuels (corrected for depletion). These latter estimates were then converted to investments for an increase of 1 barrel per day (bbl/d) of production (corrected for depletion) using the 1980 ratio of crude oil reserves to crude-oil production and assuming an 8 percent refining loss. **The ratio of** reserves to production for natural gas was not used because price controls on natural gas tend to inflate this ratio and thus the estimated costs; and investments for oil exploration and development were not separated from those for natural gas because there is no practical way to do SO.

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*One barrel of oil equivalent = 5.9 MMBtu.

**It does not, however, avoid the problem that the different parties making the investments will have fundamentally different constraints on and perspectives about these investments and thus will react quite differently in the face of investments of the same size.

Table 11 .—Estimated Investment Costs for Conventional Oil and Natural Exploration and Development

Year	Estimated investment cost (thousand 1980 dollars per barrel per day of petroleum production[)]	
	Estimate A[b]	Estimate B[c]
1974	13	15
1975	17	19
1976	20	17
1977	22	20
1978	29	18[,] 57[d]
1979	31	
1980	Not available	39"
Extrapolated to 1985[f]	53	49

a Assumes 8-percent refining loss and a 1980 ratio of crude oil reserves to production of 3.07 x 10' barrels of reserves per barrel per day production. If EIA data for petroleum reserves are used, the figures are increased by about 10 percent.

b Investment cost per barrel of increased reserves from A. T. Guernsey, "Economics of Domestic Crude Oil and Natural Gas Exploration and Development 1959-1976," December 1977, and "1977 and 1976 Addendum," June 1979, Prepared for Exploration and Production Department, Shell Oil Co., Houston, Tex.; and W. C. Hamber, Manager, Forecasting, Exploration and Production Economics, Shell Oil Co., Houston, Tex., private communication, Nov. 11, 1981

c Investment cost per barrel of increased reserves for the 26 major energy companies in the United States calculated for OTA by John Rasmussen, Economics and Statistics, Energy Markets and End Use, EIA, October 1981, based on EIA and American Petroleum Institute data See also "Performance Profiles of Major Energy Producers 1979," EIA, U.S. Department of Energy, DOE/EIA-0206(79), July 1981.

d This estimate is anomalously high due to downward revision of estimated reserves by Texaco during the year and because Ashland Oil sold aome of its crude oil reserves to a company not included in a sample of 26 major energy companies.

e This estimate may be low because petroleum reserve additions are overstated due to the purchase of Texas Pacific Oil & Gas (not one of the 26 major companies included in the calculation) by Sun Oil Co. (one of the 26 major energy companies Included in the calculation).

f Based on least squares fit of 1974-80 data, exclusive of 1979 data in estimate B. Correlation coefficient la 0.985 for estimate A and 0.82 for estimate B.

SOURCE: Office of Technology Assessment.

There are significant uncertainties in these estimates due to numerous anomalies in the data, some of which are detailed in footnotes to table 11, and because the ratio of reserves to production changes with market prices, production techniques (e. g., enhanced oil recovery), and the nature and quantity of reserves. Nevertheless, these data do indicate that it is reasonable to expect costs of $50,000/bbl/d or more for conventional petroleum exploration and development by the mid-1 980's if recent cost trends continue.

Automobile Fuel Efficiency

OTA's estimates of the investment plus associated product development costs for increased automobile fuel efficiency are shown in table 12.

There are notable technical, accounting, and market uncertainties associated with this type of cost analysis, however.

The estimates in table 12 were derived by first estimating the efficiency gains that can reasonably be expected over time from various changes in the automobile system. They are based on both published estimates and OTA's analysis. The rates at which these technologies may be incorporated into new cars were then estimated and resultant schedules for capital turnover derived. Next, the investment cost calculations were based on published estimates for the cost of replacing the applicable capital equipment (e.g., facilities for producing a new engine or transmission, etc.). The actual investment cost and resultant fuel efficiency increases, however, will depend on a number of factors specific to individual production plants (and their future evolution), the way various production tradeoffs are resolved, and the results of future product development programs.

In addition to capital investment, development costs have been included as part of the investment necessary to produce modified vehicles. During the 1970's, domestic auto manufacturers' R&D (mostly development) costs averaged from 40 to 60 percent of their capital investments.[6] In table 12, development costs are assumed to be 40 percent of the capital investment allocated to fuel efficiency (see below), but the actual costs of developing the technologies for producing more efficient cars at minimum cost are highly uncertain. *

Beyond the uncertainties in the investment and development costs, there is the problem of determining what fraction of the investments should be ascribed to fuel efficiency. This arises because some of the investments can be used not only to increase fuel efficiency, but also to make other

[6] G. Kulp, D. D. Shonka, and M. C. Halcomb, "Transportation Energy Conservation Data Book: Edition 5," Oak Ridge National Laboratory, ORNL-5765, November 1981.

*It should be noted that R&D costs are not included for synfuels because several essentially identical synfuels plants could be constructed with little additional R&D costs beyond those needed for the first plant, whereas product and process development are necessary for each major change in automobiles.

Table 12.—Capital Investment Allocated to Fuel Efficiency Plus Associated Development Costs

Time of investment	Mix shift	New-car fuel efficiency at end of time period*(mpg)	Average capital investment plus associated development costs[b]	
			Thousand 1980 dollars per barrel per day oil equivalent of fuel saved[c]	1980 dollars per car produced[d]
1985-1990	Moderate[e]	38-48	20-60[g]	50-1909
	Large[f]	43-53		
1990 -1995	Moderate[e]	43-59	60-1309	70-1809
	Large[f]	49-65		
1995-2000	Moderate[e]	51-70	50-1509	50-1509
	Large[f]	58-78		

a EPA rated 55/45 percent city/highway fuel efficiency of average new car.
b Development costs assumed to be 40 percent of capital investment allocated to fuel efficiency (see text). One barrel of oil equivalent contains 5.9 MMBtu.
c Averages are calculated by dividing average investment for technological improvements by fuel savings for average car at end of time period relative to average car at beginning of time period. The resultant average cost per barrel per day is lower than a straight average of the investments for each car size because of mathematical differences in the methodology (i.e., average of ratios v. ratio of averages) and because extra fuel is saved due to demand shift to smaller cars. The averaging methodology used is more appropriate for comparisons with synfuels because it relates aggregate Investments to aggregate fuel savings. It should be noted that the cost of adjusting to the shift in demand to smaller-sized cars is not included. Only those investments which increase the fuel efficiency of a given-size car are included.
d Assuming investment is used to produce cars for 10 Years, on the average.
e Moderate shift in demand to smaller cars. Percentage Of new cars sold in each size class are:

Year/size class	Large	Medium	Small
1985	35	60	5
1990	25	60	15
1995	20	55	25
			35

f Large shift in demand to smaller cars. Percentage of new cars sold in each size class are:

Year/size class	Large	Medium	Small
1965	15	75	10
1990	5	65	30
1995	5	45	50
2000	5	25	70

g Within uncertainties, the costs are the same for both mix shifts.

SOURCE: Office of Technology Assessment.

changes in the car. * The cost allocation problem associated with multipurpose investments is well known in accounting theory, and there is no fully satisfactory solution to it.[7]

For table 12, it was assumed that 50 percent of the cost of engine and body redesign, **75** percent of the cost of most transmission changes, and 100 percent of the cost of advanced materials substitution and energy storage and automatic engine cutoff devices should be allocated to fuel efficiency. This results in between 55 and 80 percent of the investments being allocated to fuel efficiency, depending on the time period and scenario chosen. For further details on how this and other problems in estimating the cost of fuel efficiency were resolved, see chapter 5.

*For **example, automobile designs with low aerodynamic drag may be preferred by consumers on esthetic grounds; front wheel drive may be introduced to improve traction and increase interior volume; microprocessor control of carburetion or fuel injection, spark advance, exhaust gas recirculation, and other operating conditions can be used to reduce exhaust emissions, improve performance, and enable the use of lower octane fuels; continuously variable transmissions may be introduced to produce smoother acceleration and improve performance. These and many other changes can also be exploited to improve fuel efficiency.**

7A. L. Thomas, "The Allocation Problem in Financial Accounting Theory, " American Accounting Association, Sarasota, Fla., 1969, pp. 41-57, and A. L. Thomas, "The Allocation Problem: Part Two, " American Accounting Association, Sarasota, Fla., 1974.

During the period 1985-2000, total capital investments in changes associated with increasing fuel efficiency (i.e., allocating 100 percent of the multipurpose investments to fuel efficiency) could average $2 billion to $5 billion per year, depending on the number of new cars sold and the rate at which fuel efficiency is increased. However, if one deducts the cost of changes that would have been made under "normal" circumstances, * the added capital investment needed to achieve the lower mpg numbers in table 12 would be $0.3 billion to $0.7 billion per year. The higher mpg numbers in table 12 would require added capital investments (above "normal") of $0.6 billion to $1.5 billion per year. Adding 40 percent of the capital investment for development costs results in added outlays of $0.4 billion to $0.9 billion per year and $0.8 billion to $2 billion per year for the low and high scenarios, respectively.

A detailed examination of the scenarios presented in chapter 5 shows that a 1990 new-car

*Assuming "normal" capital turnover is: engines improved after 6 years, on average, redesigned after 12 years; transmissions same as engines; body redesigned every 7.5 years; no advanced materials substitution.

average fuel efficiency of 35 to 45 mpg (depending on the proportion of small, medium, and large cars sold) probably can be achieved with what is termed here "normal" rates of capital turnover. However, the validity of this conclusion and of the above incremental investment and development cost estimates will depend on market demand for fuel efficiency, and, in OTA's judgment, there is no credible way to predict future market demand for fuel efficiency.

Electric Vehicles

Use of EVs more nearly approximates synfuels than increased automobile fuel efficiency, in that EVs involve switching from conventional oil to another energy source rather than reducing energy consumption. Consequently, the costs (per barrel per day of oil replaced) for EVs are included in table 13 with synfuels. As shown in table 13, the costs for EVs appear to be significantly higher than for the various synfuels options, due to the high purchase price of the vehicle (relative to a comparable gasoline-fueled car) and the fact that EVs would be replacements for relatively fuel-efficient cars (because of an EVs limited size and acceleration). Furthermore, if bat-

teries must be replaced at regular intervals and the cost of this is included as an investment cost, the total investment per barrel per day rises dramatically.

Synfuels

The best available estimates for the investment costs for various liquid synthetic transportation fuels are shown in table 13. Because of uncertainties in the cost estimates, no meaningful intercomparison among synfuels on the basis of cost is currently possible. In addition, as discussed in chapter 6, the final investment in synfuels is likely to be different from these estimates. As the processes approach commercial production, they will be revised as costs to overcome problems encountered in demonstration units are determined. Construction costs will inflate at an unknown rate relative to general inflation. And delays during construction due to such possibilities as lawsuits, strikes, late delivery of construction materials, or other causes can increase the investment cost. In sum, current investment estimates provide a very tentative guide to what synfuels plants constructed in the 1990's will cost. In addi-

Table 13.—Investment Cost for Various Transportation Synfuels and Electric Vehicles

	Thousand 1980 dollars per barrel per day oil equivalent to end users				
	Shale oil	Methanol from coal	Coal to methanol and Mobil methanol to gasoline	Direct liquefaction	Electric vehicle
Mining	(Included in conversion plant)	4-15	4-15	4-15	5-19
Conversion plant	49-73[a]	47-93[a]	53-110[a]	67-100[a]	0-69[b]
Refinery.	0-10'		0	4-22[d]	0
Distribution system.	0	0-2[e]	0	0	
End use.	0	0-11[f]	0	0	320°3909
Total	49-83	51-121	57-125	75-137	325-478

[a]Range of investments in ch. 6 plus possible 50-percent cost overrun and assuming plants operate at 90 percent of rated capacity
[b]Upper limit corresponds t. case where new coal-fired electric generating capacity would be needed. That is not currently the case, however.
[c]Upper limit corresponds to a dedicated refinery.
[d]Upper limit from UOP and Systems Development Corp., "Crude Oil v. Coal Oil Processing Comparison Study," DOE/ET/03117, TR-80/009-001, November 1979. Inflated by 12 percent to reflect 1980 cost. Assumes a refinery dedicated to conversion facility. Lower limit from "SRC-II Demonstration Project, Phase Zero, Task No. 3, Market Assessment Transportation Fuels From SRC-II Upgrading," Pittsburgh and Midway Coal Mining Co., prepared for U.S. Department of Energy, July 31, 1979. Assumes only upgrading of liquid for use as feedstock in an existing refinery.
[e]Upper limit assumes that half of capacity must use newly constructed or expanded facilities, as follows: 500-mile pipeline at $1 million per mile, 500,000 bbl/d capacity; tank truck (9,200 gal) costing $90,000, 10 runs per week: storage tanks and pumps costing $700/bbl/d of throughput.
[f]Upper limit assumes new engine design costing $540 million for a 500,000 car per year factory;0.15 capital recovery factor; replacing car consuming 250 gal of gasoline/yr. Beyond the initial investment in new engine production facilities, the investments are the same as for a gasoline engine, making the added investment zero, relative to gasoline vehicles.
[g]Assumes an electric vehicle costs $3,000 more than a comparably performing gasoline-powered car and the electric vehicle replaces 8,000 to 10,000 miles/yr that would have been driven in a 60-mpg gasoline- or diesel-fueled car. if batteries must be replaced every 10,000 miles (nine times over life of car) at a cost of $2,000 each time, the total investment becomes $2.7 million/bbl/d replaced. These calculations assume that no oil is used in the electric generating facilities; however, if oil is used to generate part of the electricity, the investment costs per barrel per day of oil displaced grow rapidly,

SOURCE: Office of Technology Assessment,

tion, they most likely represent a lower limit of the synfuels investment costs. *

Stationary Uses of Petroleum

OTA has also considered the costs of conservation and fuel switching in stationary uses of oil, although not in the same detail as for synfuels and increased automobile fuel efficiency. The major candidates are the residual and distillate fuel oils still used in stationary applications after 1990. Other stationary uses of petroleum—asphalt, petrochemical feedstock, still gas, and liquefied petroleum gas (LPG)—were not considered to be major potential supplies of increased transportation fuels. Although LPG can technically be used as a transportation fuel, and petrochemical feedstocks can be replaced by synthesis gas from coal, a preliminary analysis indicates that the fuel oils are more economically attractive alternatives for increasing supplies of transportation fuels in most cases.

OTA's estimates for the investment costs of fuel switching and increased energy efficiency in stationary uses during the 1990's are shown in table 14. Although only single numbers are shown, in fact there will be a range of costs depending on development costs for new energy supplies, installation costs for end-use equipment, the extent of changes needed at oil refineries, and variations in conservation investments. Of the fuel switching options the range is narrowest for fuel switching to electricity because of the fairly well-defined

"Decisions about whether and how quickly to proceed with investments in synfuels production, however, will be strongly influenced not only by estimated costs but by corporate strategy.

cost of producing electricity from coal and largest for fuel switching to natural gas because of differences in the cost of developing various unconventional gas supplies.

In deriving the numbers in table 14, it was assumed that the lower cost opportunities for fuel switching and conservation would already have been carried out by 1990. To the extent that this does not occur, the per-unit investment cost estimates for the 1990's would be lowered somewhat. Also, increased end-use efficiency of electricity for heat and hot water would reduce the investment needed for electric powerplants; and if large supplies of relatively inexpensive gas are found, fuel switching to gas could be a very attractive option, in terms of capital investment. Because of these uncertainties and site-specific differences in installation costs, one cannot clearly choose among the alternatives on the basis of investment costs alone. All of the options to eliminate stationary fuel oil use seem to require the same order of magnitude of investments.

Conclusion

Three principal conclusions emerge from OTA's analysis of investment costs for the various ways of reducing oil consumption. First, there is a great deal of uncertainty about investment costs due to technological unknowns, lack of experience, and site-specific cost differences. * Second,

*The situation is further complicated by the different nature of the investments. Synfuel plant construction requires large investments over a number of years before any product is sold. Auto industries tend to make incremental changes in capital stock, with the sum of several such investments sometimes costing more than one abrupt changeover in capital stock. Investments in fuel switching and conservation are paid back through future fuel cost savings rather than product sales.

Table 14.—Estimated Investment Cost of Fuel Switching and Consecration in Stationary Petroleum Uses During the 1990's

Investment at	Thousand 1980 dollars per barrel per day of oil replaced or saved				
	Conversion to natural gas	Conversion to electricity	Conversion of boilers from residual fuel oil to coal		Increased efficiency and fuel switching
End use equipment	24	32	37	(51)[a]	88
New production of fuel	90	78[b]	16[c]	(22)[a]	0
Total	114	110	53	(74)[a]	88

The number in parenthesis is corrected for the 72-percent efficiency of refining residual fuel oil and is the Investment per barrel per day of resultant distillate oil produced from the residual 011.
[b]Construction of coal-fired powerplant ($74,000) Plus new coal mining (S4,400).
[c]Modification of refineries to upgrade residual oil to distillate fuels, $14,000, and increased coal production, $2,000. The refinery modification is based on data presented in ch. 6, assuming that 0.6 MMB/D of domestically produced residual oil is already being upgraded in 1990.

SOURCE: Office of Technology Assessment.

even if more certain cost data were available to-day, different inflation rates in different sectors of the economy or modest technical developments could change any conclusions about relative costs by the 1990's. Finally, once the initial investments to reduce oil consumption have been made, the annual capital investment needed to maintain all aspects of liquid fuel production and use will depend on the level of fuel efficiency actually achieved. In particular, high levels of efficiency in end uses will require lower levels of annual capital investment.

Box A.-Consumer Cost of Increased Automobile Fuel Efficiency

For the purposes of this section, the consumer cost of increased fuel efficiency was defined to be the added cost of producing a more fuel-efficient car (relative to an otherwise comparable but less efficient car) per gallon of fuel saved by using the more efficient vehicle. The added cost of producing more fuel-efficient cars will depend not only on the investments needed to change automobile production facilities and the production volumes, but also the resultant changes in the variable costs* of production, such as changes in materials and labor costs.

As discussed *on page* 75, the capital investments that are needed to increase fuel efficiency also produce other changes in automobiles; and allocation of costs among fuel efficiency and the other changes is somewhat arbitrary. In addition, if market demand for fuel efficiency is strong, many changes that increase fuel efficiency would be incorporated into the normal capital turnover of the industry. For the purpose of calculating consumer costs, however, essentially the same approach was taken as with the investment cost estimates. The fraction of investments allocated to fuel efficiency are the same as for the investment costs per barrel per day of fuel saved; and only the average costs per average gallon saved have been calculated-relating each 5-year period to the previous 5-year period —rather than compounding errors by assuming some market-driven scenario as a point of reference.

In addition, it was assumed that production volumes are sufficiently large so that there are no significant diseconomies from small-scale plants or losses from underutilized facilities. Weak demand for fuel efficiency and/or for new cars in general could of course result in additional costs of this sort.

A key factor in consumer costs is the change in variable costs associated with producing more fuel-efficient vehicles. Variable cost estimates,

● Variable production costs are those that vary in proportion to the number of units produced as opposed to fixed costs such as capital charges.

however, are generally proprietary and can vary considerably from one company to another. Furthermore, changes in variable costs with increased fuel efficiency will depend, to a large extent, on the success of efforts to develop production technologies that can hold down production costs. Some of the uncertainties in variable cost changes are discussed below, followed by illustrative examples of plausible consumer costs for increased fuel efficiency.

Some changes that increase fuel efficiency will lower variable costs; some will increase some variable costs while lowering others; and still other changes are likely only to increase variable costs.* However, factors which are only peripheral to the nature of the technology incorporated in the car often dominate the change in variable costs, These factors include: 1) the existing nature and layout of equipment in the plant being modified to produce the new car, 2) various specific production decisions (e.g., which of various processes is used in manufacturing a component, what equipment will be modified, what will be the production volume), and 3) the success of developing new, lower cost procedures for producing a component and assembling it in the vehicle. In other words, the net change in variable costs depends not only on the nature of the new technology and the way it is produced, but also on the path the manufacturer has chosen to evolve from the current production facilities and configurations to those needed to produce the more advanced tech nol-

*For example, reducing automobile size and weight by reducing the quantity of materials reduces variable costs. Switching to lighter weight materials has the side effect of reducing the needed size of axles, auto frame, ate,, which reduces costs; but the higher cost of the new material and increased difficulty of handling that material (e.g., molding, casting, welding, finishing, painting, heat treating) can increase variable costs. Similarly, producing a more efficient engine may enable reduction in engine size, number of cylinders and complexity of the pollution control equipment, which reduces costs; *but* the need for more precise machining and possibly added equipment (e.g., turbochargers) can raise the variable costs. Finally, changes such as going from a three-speed transmission to a four-speed, five-speed, or continuously variable transmission are likely to increase variable costs because of increased complexity and materials and processing requirements.

ogy. Furthermore, as with capital investment, there is the problem of deciding what fraction of an increase in variable cost should be ascribed to fuel efficiency. Because of these problems and ambiguities, anything more than a brief overview of the range of possibilities would not be justified.

Various recent estimates of variable cost changes can serve to illustrate the effect of this component on the overall consumer cost of producing more fuel-efficient cars. For example, successful development of production techniques and continued market pressure on automobile companies could hold down production costs so that more fuel-efficient cars can be produced without any large change in manufacturing variable costs. Although some costs will go up, others will drop and the net effect will be little or no change. On the other hand, data presented in a recent analysis based on proprietary automobile industry estimates indicates a substantial increase in variable costs. The apparent increase in variable costs ranges from 60 to 250 percent and averages 170 percent of the costs associated with the capital investments (capital charges) during the period 1985-2000.

To illustrate the effect of this range of variable costs on the ultimate cost to the consumer, a series of calculations were made in table 15. It

is assumed that the consumer does not discount future fuel savings and that each car is driven 100,000 miles over its lifetime. The range is calculated by first assuming that the increase in variable costs is negligible, and second that it is twice the capital charges allocated to fuel efficiency (see p. 76). The apparent consumer cost per gallon of fuel saved would be about 2.5 times as large as the numbers shown if the consumer discounts future fuel savings at 25 percent per year.* Similarly, the apparent cost per gallon of fuel saved will decrease if the car is driven more than 100,000 miles and increase if the car is driven less than that.**

As these examples illustrate, the consumer cost of increased automobile fuel efficiency can vary over a wide range. The cost will depend not only on technical developments and the success automakers have at holding down production costs, but also on consumers' perceptions and accounting procedures, which change with time. As a result, accurate consumer costs probably cannot be derived until production techniques have been developed and proven in practice and market preferences of consumers can be determined.

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[1] Richard L. Strombotne, Director, Office of Automotive Fuel Economy Standards, National Highway Traffic Safety Administration, U.S. Department of Transportation, private communication, 1981.

[2] Richard H. Shackson and H. James Leach, "Maintaining Automotive Mobility: Using Fuel Economy and Synthetic Fuels to Compete With OPEC Oil," Energy Productivity Center, Mellon Institute, Arlington, Va., interim report, Aug. 18, 1980. Variable cost changes were deduced from the estimates of capital investment and changes in consumer costs by assuming an annual capital charge of 15 percent of the investment and deducting this capital charge from the consumer cost estimates.

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*In other words, the consumer values next year's fuel savings 25 percent less than this year's; savings that will occur during the year after next are valued 25 percent less than next year's, and so on.

**Although the person who buys a new car is unlikely to own it for the full 100,000 mile life of the car, the resale value of a more expensive car is also likely to be higher. The cost of a more fuel-efficient car will, in practice, depend on the difference between the purchase and (later) resale price of that car, relative to a less fuel-efficient one. Once the car has been sold and resold several times and finally junked, however, the total cost to all owners per gallon of fuel savings will depend on how far the car has been driven in total.

Table 15.—Plausible Consumer Costs for Increased Automobile Fuel Efficiency Using Alternative Assumptions About Variable Cost Increase

| | | | Consumer cost[a] ($/gal gasoline saved) | |
| | | | Assuming no variable cost increase relative to 1985 variable costs of production | Assuming variable cost increase equal to twice the capital charges |
Time period	Mix shift[b]	Average fuel efficiency at end of time period (mpg)		
1985-90	Moderate	38-48	0.15-0.40[c]	0.40-1.10[c]
	Large	43-53		
1990-95	Moderate	43-60	0.35-0.85[c]	1.10-2.60[c]
	Large	48-65		
1995-2000	Moderate	51-70	0.30-0.95[c]	0.90-2.90[c]
	Large	56-78		

[a] Assuming capital charges of 0.15 times capital investment attributed to fuel efficiency, life cycle costing, and car driven 100,000 miles during its lifetime.
[b] See table 12 for definitions of mix shifts.
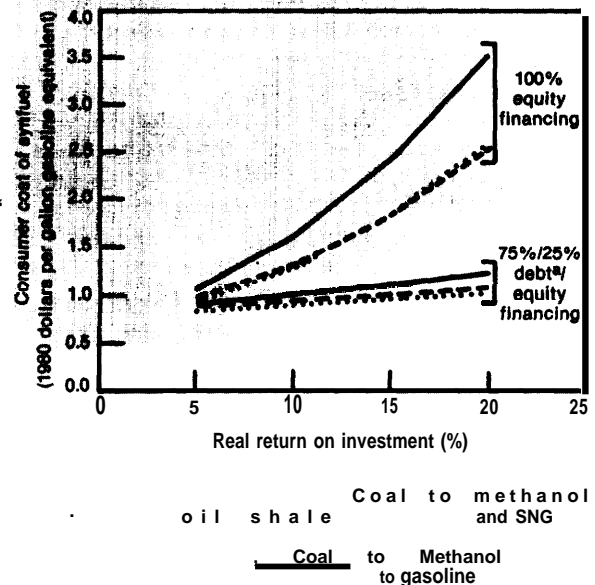[c] Within the uncertainties the costs are the same for each mix shift.

SOURCE: Office of Technology Assessment.

Box B.-Consumer Cost of Synfuels

The consumer cost of synthetic transportation fuels will depend on a number of factors. The most important of these are the actual capital investment needed to build the synfuels plant, the way plant construction is financed, the required return on investment, the cost of delivering the fuel to the end user, and the end-use efficiency of the synthetic product. For the first generation of synfuels plants, the costof producing the synfuel will also depend critically on plant performance, specifically the amount of time the plant is operated Mow its rated capacity due to the technical problems. (See ch. 6 for a more detailed sensitivity analysis.) Depending on assumptions about these factors, one can derive a wide variety of consumer costs.

Table 16 shows two sets of consumer costs for various fossil synfuels. These costs are based on the best available investment and operating cost estimates and assume no cost overruns, good plant performance (90 percent of rated capacity), a lo-percent real return on equity investment* and two financing schemes: 100-percent equity financing and 75/25 percent debt* */equity financing. Figure 5 shows how these con-

*In other words, a return on investment that is 10 percent higher than general inflation.
● *The debt must be.project.specific, i.e., the money is loaned for the specific project and is not general debt capital whose *payback* is guaranteed by other company assets.

Figure 5.-Consumer Cost of Selected Synfuels With Various Returns on Investments

5% real interest rate on debt.

SOURCE: Office of Technology Assessment.

Table 16.-Estimated Consumer Cost of Various Fossil Synfuels Using Two Financing Schemes

Liquid transportation fuel	Cost of Synfuel delivered to end user[a]($/gallon gasoline equivalent)	
	100% equity financing[b]	75% debt, 25°A equity financing
Reference cost of gasoline from $32/bbl crude oil	1.20	
Shale oil		
Methanol from coal	1.30[d](1.10)[e]	0.95[d](0.80)[e]
	1.60[f](1.30)[e]	1.10 (0.90)[e]
Coal to methanol with	1 . 2 5[d]	0.80[d]
Mobil methanol to gasoline.	1 . 6 0[g]	1.00[g]
Coal to gasoline via Fischer Tropsch Synthesis	1.30[d]	0.85[d]

[a]Assumes $0.20/physical gallon delivery charge and service station mark-up. Note that delivered methanol usually costs more per gallon of gasoline equivalent (gge) than delivered gasoline from methanol because the delivery charge per gge is twice as high for methanol as for gasoline, due to the lower energy content of the former.
[b]10-percent real return on investment
[c]10-percent real return on equityinvestment, 5-percent real investment on debt.
[d]Involves coproduction of synthetic natural gas.
[e]Numbers in parentheses assume methanol ueed in engine designed for methanol use which is 20 percent more efficient than a amapondmg gasoline engine.
[f]Methanol is principal product.
[g]Gasoline is principal product.
SOURCE: Office of Technology Assessment.

sumer costs change with the required rate of return on investment.

As mentioned above, plant performance is an important determinant of the cost of synfuels from the first generation of plants. Because the selling price of the synfuels probably will be determined by the competing price of petroleum fuels, poor plant performance may translate into a low return on investment or a financial loss. In recognition of this possibility and the large number of very profitable investments currently available to the energy industry, most investors are likely to require a high potential rate of return on investment before proceeding with a synfuels project.

In other words, in the absence of loan guarantees to enable high debt financing, conventional liquid fuel prices could easily have to exceed $2.00/gal of gasoline equivalent (1980 dollars) before synfuels would be widely perceived as a good risk.* Once the technologies are commercially proven, however, fuel prices shown in table 16 could provide adequate incentives for investment, provided that the solution of any technical problems uncovered in the first commercial plants does not significantly increase the required plant investment.

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*Some companies in a good capital position might be willing to take the higher risk to gain experience and/or an early market share, however.

Box C.—Total Cost and Investment Cost

In comparing the costs of the various options for reducing conventional oil consumption, we have, for three reasons, emphasized investment costs, rather than total costs (or consumer costs) per unit of oil saved or replaced. First, consumer costs are considerably less certain than investment costs because of site-specific factors and technical and financial uncertainties. Second, because different consumers will discount future fuel savings at quite different rates, the total costs seen by consumers will be highly variable (even for the same option). Furthermore, the costs of the various options require different proportions of investment costs (which may be discounted) to changes in operating costs (which are not discounted). Finally, each of the options for reducing oil consumption is capital-intensive and it will require hundreds of billions of dollars in investments to reduce oil imports significantly; these investments will come at the expense of other investments in the economy and direct consumption. From a national perspective, it is important to compare the options with respect to the investment needed per unit reduction in oil use to see if any of the options is significantly less capital-intensive than the others.

Total cost to consumers (per unit oil saved or replaced) does, however have a strong influence on the extent to which each option actually/ is implemented. Although specific values for the total cost to consumers are not given here, some of the uncertainties in, and factors influencing, total cost are discussed below. It should be em-

phasized, however, that the costs of some of the options may not equal the price. Price will be determined by market forces.

Increased Automobile Fuel Efficiency

Fuel efficiency cannot be neatly separated from other attributes of a car, and there is always a certain ambiguity in determining what fraction of production costs should be ascribed to fuel efficiency. In addition, depending on the demand for fuel efficiency, varying fractions of the investments associated with increasing fuel efficiency could be ascribed to and incorporated in "normal" capital turnover in the auto industry.

Beyond these accounting difficulties, there are uncertainties in the investments needed to make various changes in automobile production facilities and in the size of the resultant fuel-efficiency increases. And another important factor affecting total cost is any change in variable costs (materials and labor) associated with producing more fuel-efficient cars. Whether or not variable costs increase will depend on the success of adapting and developing low-cost processes for manufacturing the more fuel-efficient cars, and the outcome of the development efforts cannot be readily predicted.

A final area of uncertainty involves the rate that consumers discount (i.e., how much they value) future fuel savings. For example, discounting future fuel savings at 25 percent per year in-

creases the apparent cost of fuel efficiency per gallon saved by a factor of 2.5 over the situation where no discount is applied to future fuel savings. In practice, there will be a wide variety of discounting rates used by various consumers, and the rates will change with market conditions (including oil prices and interest rates) and consumers' beliefs about future oil prices and availability, among other things.

Synthetic Fuels

For synfuels processes that produce sizable quantities of different fuel products (e.g., synthetic natural gas and fuel oil), one encounters accounting problems similar to those discussed under increased automobile fuel efficiency-i.e., how to allocate production costs to the various synfuels products. However, these problems are less severe for synfuels than for automobiles because all of the major products of the former are separate consumer products with known current prices. Furthermore, the accounting problems can be largely avoided by considering only processes that produce only fuels of similar quality (e.g., gasoline, jet, and diesel fuel), and avoided entirely by considering processes that produce only one major product.

Variations in operating and maintenance costs and future coal prices produce some uncertainty in the cost of synfuels. The more important uncertainties, however, involve the cost of building a synfuels plant, how this cost will be financed, and investors' required rates of return on investment. The cost of synfuels from the first generation of synfuels plants will also depend critically on plant performance, with frequent shutdowns and repairs increasing costs dramatically. Presumably, later generations of plants will perform reliably.

Fuel Switching and Conservation

The total cost of switching utility boilers from fuel oil to coal is fairly welt known. There are, however, some areas of the country where coal is not readily available, and there is insufficient space to accommodate coal handling facilities at some electric generating plants.

The major variability in the cost of switching to natural gas and electricity for buildings and in industry results from widely varying required rates of return on investments in different industries and for different building owners or renters. At some sites, though, natural gas is not available or space limitations prevent the installation of gas facilities. There is also uncertainty in the cost of finding and processing unconventional natural gas (from tight sands, etc.).

The total cost of conserving heat and hot water in buildings is probably the least certain of the measures for reducing stationary oil use. Not only are there large uncertainties and variability in the savings that can be achieved through various conservation measures, but also consumers will discount future fuel savings at widely differing rates.

HOW DO THE ENVIRONMENTAL IMPACTS OF INCREASED AUTOMOBILE FUEL EFFICIENCY AND SYNFUELS COMPARE?

The synfuels, auto fuel efficiency, and electric auto alternatives for displacing imported oil have sharply different potential impacts on public health and safety, on workers, and on ecosystems. In addition, probabilities of these impacts actually occurring—few of them are inevitable—are also quite different. Both the potential impacts and their risks are briefly compared below. The nature of some of the risks, however, is obscured by the brevity of the following discussion. For example, the actual risk associated with possible contamination of drinking water by synfuels production is heavily dependent on the degree of prior recognition of the risk and response to this recognition –for example, development of ground water monitoring systems. Also, risks that are similar in magnitude are often valued differently because of the degree of choice involved (e.g., willing exposure to the risks of auto travel v. unwilling exposure to accidental toxic spills) and the precise nature of the risks (e.g., multiple automobile accidents involving only a few peo-

ple **at a time v. a serious accident or control failure at a large synfuels plant).**

Public Health and Safety

Reductions in vehicle size, part of the auto fuel-efficiency measures, could have the strongest effect on public health and safety through their potential adverse effects on vehicle safety. The effect is difficult to estimate because of a lack of comprehensive traffic safety data that would allow an evaluation of the relative effect of car size and other key safety variables on vehicle crash-'worthiness and accident avoidance, and because of uncertainty about the compensatory measures that might be taken by the vehicle manufacturers and by drivers. Although the National Highway Traffic Safety Administration has projected vehicle size reductions to cause an additional 10,000 annual traffic deaths by 1990 if compensatory measures are not taken, this and other quantitative estimates of changes in traffic safety are based on limited data and relatively crude models. Nevertheless, an increase in traffic deaths of a few thousand per year because of vehicle size reductions does seem plausible.

Diesel use could have an adverse effect on emissions of nitrogen oxides (NO_x) and particulates, and conceivably could cause public health problems in congested urban areas. The risk is moderated, however, because: 1) controls for NO_x and particulate are under active development, although success is not assured and it is possible that the current level of effort will not be continued; and 2) the evidence for health damage from diesel particulate is equivocal.

Electric passenger vehicles are likely to be small, and thus should share safety problems with radically downsized high-mileage conventional automobiles. Additional safety problems caused by the batteries, which contain toxic chemicals that may be hazardous in an accident-caused spill, are offset somewhat by eliminating the fuel tank with its highly flammable contents. Also, electric cars should have a positive effect on air quality, especially in urban areas, because the reductions in automobile emissions outweigh increased emissions from powerplants, except for sulfur dioxide (SO_2).

Synfuels plants may expose the general public to health and safety hazards in a variety of ways: contamination of drinking water from leaching of wastes, accidental spills, or failure of effluent controls; accidental release of toxic vapors; exposure to contaminated fuels; and routine emissions of conventional air pollutants such as SO_2 and NO_x. Only the routine emissions are essentially inevitable, however, and health and safety problems from these should be minimized by Federal ambient air quality standards and by the relative magnitude of these emissions, which should be considerably lower than emissions from projected levels of development of coal-fired electric generation during the same time frame. The extent of risk from the other sources is not well understood because the toxic waste streams from the plants have not been fully characterized, the effects of some of the known and suspected waste products are not yet well understood, and the effectiveness and reliability of some critical environmental control systems have not been demonstrated under synfuels plant conditions (see issue on p. **95). Chemical industry** sources believe that few problems will arise, but, as discussed in the above-mentioned issue, some areas of concern remain.

Worker Effects

With the possible exception of some worker exposure to toxic materials in battery manufacture, the only significant occupational health and safety problem associated with the automobile measures appears to be mine safety and health effects involved in any increased mining of coal for electricity needed for recharging electric car batteries, and, to a lesser extent, for aluminum manufacture. These impacts are not trivial, because the amount of coal needed per *barrel of oil* saved for electric cars is of the same order of magnitude as that needed for synfuels production (assuming coal-fired electricity and coal-based synfuels). The coal-to-oil balance for aluminum use is somewhat less certain, although some analyses have calculated it to be similarly high. The use of aluminum is not the major part of the efficiency measures, however, and the actual amount of coal required is not likely to be significant in comparison with the coal used for synthetic fuels.

As noted, synfuels production has a coal requirement similar to that of electric autos, and thus shares similar mineworker problems. It has important additional problems. The sources of moderate risks to public health and safety—fugitive emissions, spills, plant accidents, and contaminated fuels–pose more serious risks to workers because of their frequency and severity of exposure. For example, workers will be continuously exposed to low levels of polynuclear aromatics and other toxic substances because fugitive emissions cannot be reduced to zero. Another important source of possible worker exposure is the maintenance requirements of synfuels reactors; the materials that must be handled in these operations are likely to have the highest concentrations of dangerous organics.

Exposure to hazardous substances is common in the petrochemical industry, and worker-protection strategies developed in this and related industries will be used extensively in synfuels plants. These strategies clearly will reduce the hazards, but the degree of reduction is highly uncertain (see issue on p. 95).

Ecosystem Effects

The only significant sources of ecosystem effects from the automobile measures are likely to be the changes in air quality caused by the use of electric autos (which probably will be positive) and diesels, and the air, land, and water pollution associated with the mining and processing of both coal for electricity (for battery recharging or aluminum production) and battery materials such as lead and lithium. Obtaining the new battery materials is thought unlikely to cause important environmental problems, but there are many different kinds of potential battery materials, and final judgment probably should be withheld at this time. Nevertheless, with the exception of the electric-car coal-mining requirements, any adverse ecosystem effects of the automobile measures appear likely to be mild.

Synfuels production is likely to cause significantly greater adverse effects, because it will have coal-mining damages per barrel of oil roughly similar to electrical autos *as we//as* several additional and potentially important adverse impacts.

These include substantially increased mining and waste disposal requirements if oil shale is the synfuels feedstock, and a variety of potential adverse impacts stemming from the possibility that toxic materials generated during the conversion processes will escape to the environment. The pathways of potential damage from toxics are essentially identical to those threatening public health and safety—surface and ground water contamination, toxic vapors, and exposure (in this case from spills) to contaminated fuels. Unfortunately, probability of the damage actually occurring is equally difficult to evaluate.

An additional concern is that synthetic fuels from biomass sources–which in general have similar or less severe environmental problems than coal-based synfuels—may have more severe ecosystem effects because of the very extensive nature of their resource base. The adverse ecosystem effects of large increases in grain production to produce gasohol, for example, can be quite serious, and, given the nature of the current agricultural system, the probability of such effects occurring is high.

Summary

The environmental impacts of increased automobile fuel efficiency and synthetic fuels development will be quite different and difficult to compare. The major impacts of auto efficiency improvements are likely to be increases in crash-related injuries and fatalities from auto size reductions. The severity of these impacts is heavily dependent on vehicle design and driver behavior (especially seatbelt usage). Synthetic fuels development's major impacts will include the well-known ecosystem effects as well as public and worker health and safety effects of large-scale mining and combustion of coal. Oil shale development will have many similar effects; a most serious environmental risk may come from inadequate disposition of the spent shale. In addition, there are *potentially* serious impacts on people and ecosystems from the escape of toxic substances from synfuels conversion processes. The severity of these impacts is unclear because important waste streams have not been characterized and environmental control effectiveness and reliability has not been demonstrated.

HOW WILL THE SOCIAL IMPACTS OF SYNFUELS AND INCREASED AUTOMOBILE FUEL EFFICIENCY COMPARE?

Identifying, assessing, and comparing the social impacts of synfuels development and improved automobile fuel efficiency are difficult because these impacts will not be distributed evenly in time or among regions. Moreover, they cannot necessarily be measured in equivalent (e.g., dollar) terms, and they are difficult to isolate and attribute to specific technical choices. Both beneficial and adverse social consequences will arise from these two approaches to reducing oil imports.

Employment

Synthetic fuels production presents two major considerations about social impacts related to employment. First, there is the possibility of shortages of experienced chemical engineers and skilled craftsmen. A rapid growth in synfuels would likely put increased pressure on engineering schools, which are now suffering from insufficient numbers of faculty. The second concern arises from the large and rapid fluctuations in labor requirements for construction. While no shortages of construction workers are expected, on the average, fluctuating labor requirements during construction and startup can have severe secondary effects on communities at the construction sites. A population increase of about three to five people per new worker could occur, leading to possible population fluctuations of 30,000 to 60,000 people for some synfuels construction.

The changing structure and markets of the established automobile industry are likely to lead to a long-term, permanent decline in auto-related industrial employment. The nature of this decline will depend on import sales, the growth rate of the U.S. auto market, the competitiveness and labor intensity of U.S. manufacturing, the use of foreign suppliers and production facilities, and the adoption of more capital-intensive production processes and more efficient management practices. The skill mix will also shift increasingly towards skilled labor. Scarcities of experienced engineers and certain supplier skills could inflate the prices of skilled manpower resources for both synfuels and changing automotive technology.

Community Impacts

Synfuels development will have its most immediate effect in relatively few small and rural oil shale communities in the West, as well as in the small rural communities located near many of the Nation's dispersed coal resources. In the long term, local communities should benefit from synfuels in terms of expanded tax bases and increased wages and profits. However, in the near term, there are risks of serious disruptions in both the public and private sectors of these communities. The nature and extent of these disruptions will be determined by the community's ability to absorb and manage growth, and the rate and scale of local synfuels development.

Automobile production jobs are presently concentrated in the North-Central region of the Nation. The geographical distribution can be expected to change as inefficient plants are closed and new production facilities are established in other parts of the United States. New plants will provide new employment opportunities with accompanying community benefits (e. g., tax revenues); plant closings in areas heavily oriented towards the auto industry would deepen the existing economic problems of the North-Central region, i.e., high unemployment, rising social welfare costs, and declining tax base.

HOW DO THE REGIONAL AND NATIONAL ECONOMIC IMPACTS OF SYNFUELS AND INCREASED AUTO EFFICIENCY COMPARE?

In addition to comparisons on the basis of cost per barrel, environmental impacts and local social impacts, increased automobile fuel efficiency and synfuels can be compared on the basis of their potential regional and national economic impacts. The latter comparison is important because each type of investment implies an alternative national strategy to achieve the goals of price stability, national economic growth, and equity as well as oil import reduction.

Regional and national aggregation are also important because both industries are capital-intensive. Large blocks of investment must be mobilized, with key investment decisions made by a relatively small number of firms, based on very uncertain longrun predictions about the future. As summarized below, a variety of important national and regional issues are raised by the uncertainties and inflexibilities inherent in these decisions.

Inflation and Economic Stability

Inflation may be dampened and the economy stabilized if either type of investment is successful. In the case of synfuels, if first generation plants demonstrate competitive costs, the mere prospect of rapid deployment could moderate oil import prices and thus help to control what has been one of the major inflationary forces during the last decade. In the case of autos, if increased fuel efficiency helps domestic firms to hold or perhaps increase their market share, this would keep U.S. workers employed and at least stabilize foreign payments for autos. Higher employment also tends to reduce Federal transfer payments, which either reduces the Federal deficit or lowers taxes. Reductions or stabilization of foreign payments tends to strengthen the value of the dollar in foreign exchange markets. Both changes, in the Fed-

eral budget and on foreign accounts, reduce inflationary pressure.

On the other hand, attempts to displace oil imports too quickly may be inflationary. Risks of inflation, technical errors, and market miscalculations all increase with the rate of synfuels deployment and with shortening the time taken to convert the domestic auto fleet to high fuel efficiency.

in the case of synfuels, rapid investment growth in the next decade, beyond construction of demonstration projects, could cause inflation by creating suppliers' markets in which prices for construction inputs, especially chemical engineering services, can rise more rapidly than the general inflation rate. Deployment prior to definitive testing in demonstration plants also compounds potential losses due to design errors.

In the case of autos, rapid large-scale investments can inflate prices of vehicles as firms attempt to amortize capital costs quickly. However, if these attempts fail, presumably because buyers stop buying high-priced domestic autos, then newly invested capital must be written off prematurely, resulting in the waste of scarce resources for the firm and the Nation. Furthermore, if rapid fuel-efficiency improvements are forced by abrupt, real fuel price increases or by aggressive foreign auto competition, then the domestic auto industry and owners of fuel-inefficient cars will both be forced to absorb lump sum losses in the real value of current assets. Low prices for new cars resulting from competition do, however, benefit purchasers of these cars.

Employment and International Competition

If improved fuel economy makes domestically produced autos more competitive with imports,

there will be two major national economic pay-offs besides fuel savings. First, this improved competitiveness will protect traditional U.S. jobs; second, it will reduce the drain of foreign payments to auto exporting countries as well as to oil exporters. Synfuels do *not* present a similar coupling of economic possibilities.

There are major doubts, though, about the longrun success of U.S. automakers with foreign competition. The United States may not be able to compete in the mass production of fuel-efficient autos for a variety of reasons—such as high wages, low productivity, and inefficient or out-of-date management. All such explanations are speculative, but together they have raised serious doubts about U.S. competitiveness in the context of the recent, rapid increase in the market share of auto imports. If foreign automakers continue to drive domestics out of the market for fuel-efficient autos, synfuels investments may be preferred over investments in fuel efficiency even if the apparent cost per barrel of the former are higher.

Assuming investment in either industry does lead to increased U.S. production, employment opportunities for synfuels and autos can be compared based on 1976 data (the most recent available). Synfuels production involves mainly mining and chemical processing activities, which in 1976 dollars had $59,000 and $55,000 invested per worker respectively. On the other hand, the transportation equipment sector of the economy (which is dominated by autos) had $27,000 invested per worker and auto suppliers such as fabricators of metal, rubber, and plastic products had about $21,000 per worker. In other words, in the recent past the auto industry created about twice as many jobs per dollar of investment as industrial activities similar to synfuels. The current trend toward automation in automating will undoubtedly lower its labor intensity, but the auto industry should continue to employ more workers per unit of investment.

Income Distribution Among Regions

Another question concerns the likely regional distribution of incomes from autos and synfuels. An analysis of location factors was not carried out,

but two points can be made. First, to the extent that the auto industry could use existing plants or build nearby, current employment patterns and established communities could be maintained. This would preclude costly relocation and would tend to favor the North-Central region of the United States, which has been losing its industrial base.

Second, new auto plants can be located in more areas of the country than new synfuels plants because of the high cost of transporting synfuels feedstocks, especially oil shale, compared with the cost of transporting manufactured materials and parts for automobiles. Transportation costs are likely to concentrate synfuels investments in regions of the Nation with superior shale and coal reserves. Biomass options are least likely to be concentrated, because resources are dispersed, and coal-based options are much more flexible than shale because coal is more widely dispersed.

Capital Intensity and Ownership Concentration

Finally, both strategies for oil import substitution affect the number of profitable firms in each industry. In both industries, the number of competitive firms is severely constrained by the size of investment outlays and by the acquired knowledge of those already in the business.

In liquid fuels, the introduction of synthetic fuels sharply increases the amount of capital investment required per barrel of liquid fuels production capacity. For example, in the case of one major oil company, present capitalized assets per average daily barrel of oil equivalent of production from old reserves of conventional oil and natural gas is less than 20 percent of OTA's estimate of the similar ratio for oil shale. * However, new reserves of conventional oil and gas will also require much larger capital outlays than old reserves, due to depletion of finite natural resources.

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*Value of assets for Exxon was obtained from its 1980 Annual Report.

From the investor's viewpoint, the sequence of investments for conventional petroleum resources is very different from synfuels projects. For conventional petroleum, small operators can explore for new reserves, at least on shore, with only a relatively small amount of high-risk money and the limited technical staff required to rent a drilling rig and to determine where the wildcat well should be drilled. If a discovery is made, subsequent, much larger investments in development wells and pipelines can be made at relatively low risk. In synfuels, a firm simply cannot enter the business without command of all capital requirements up-front, or without a very large staff of technicians and managers.

In summary, investment options to discover and develop conventional oil and gas will be exploited before synthetics even if estimated total capital outlays are the same, because the former confine major risks to the front-end of projects before the largest blocks of capital must be committed.

As a result, it is likely that only a very small fraction of the hundreds of firms currently producing conventional oil and gas will have the financial and technical means to produce synfuels when conventional resources are depleted. While this growing concentration of ownership may not lead to the classical problem of price fixing by domestic producers, because oil and gas are traded on worldwide commodity markets, it does at least make the industry appear to be more monolithic, since synfuels project managers will command very large blocks of human and material resources.

In domestic automating, ownership may become more concentrated because at least two out of the three major U.S. companies are being forced, by lack of capital and perhaps by high production costs, to curtail the number of different vehicles made. Although foreign automakers are increasing their U.S. manufacturing activities, the growing dominance of one major U.S. automaker over the other two may decrease price competition in certain types of cars and possibly reduce profitmaking opportunities for domestic suppliers to auto manufacturing because of the market leverage of the one dominant buyer.

WHAT DO INCENTIVES FOR INCREASED FUEL ECONOMY IMPLY FOR THE EVOLUTION AND HEALTH OF THE U.S. AUTO INDUSTRY?

The auto industry began a process of structural changes in the 1970's which complicates evaluation of how fuel economy policy might affect the industry, auto manufacturing communities, and the national economy. Regardless of fuel economy policy, the U.S. auto industry is undergoing a long-term decline in terms of employment, the number of domestic firms (including suppliers), and the proportion of global auto production sited in the United States. Recent consumer demand for fuel economy and other auto characteristics have supported these trends by motivating costly product changes to meet competition from foreign firms. Factors such as the relatively fast sales growth in foreign auto markets and lower costs of labor and capital abroad have induced U.S. manufacturers to increase investments in foreign production activities.

Increases in demand and other pressure on U.S. firms to raise fuel economy will reinforce and perhaps accelerate current industry and market trends. Although large spending needs will motivate reductions in the number of independent firms and, perhaps, the breadth of their operations, the size and financial health of the U.S. auto industry in the future will depend, to a great degree, on its ability to compete with foreign firms–particularly in the small-car market. The competitiveness of U.S. auto firms depends not only on product designs and production facilities but also on total manufacturing costs, which reflect labor costs and the efficiency of production, organization, and management. incentives for accelerating fuel-efficiency increases will not only directly affect the investment requirements, but a combination of high perceived investment

needs, possible rigidity in U.S. costs, and a slow-growing competitive U.S. market may discourage U.S. firms from investing in U.S. capacity.

There are some auto company activities that should be relatively invulnerable to fuel economy-motivated market changes and should continue in the United States. These activities include production of specialty cars and nonautomotive projects such as defense contracting. U.S. auto companies may continue to conduct some activities in the United States at historic or greater levels, while they may reduce the levels of others or eliminate them entirely.

A decline in U.S. auto production, especially one that is not substantially offset by growth in foreign-owned capacity in the United States,

poses a major policy dilemma. On the one hand, the auto industry metamorphosis may result in a more economically efficient domestic industry that is more competitive with strong import competition. On the other hand, the process of industry change results in loss of jobs for current autoworkers and loss of employment and business activity for local economies, losses which are relatively large and regionally concentrated in the already economically depressed North-Central region. These concerns can be dealt with through industrial and economic development policies, but it should be recognized that policy to accelerate fuel economy improvements may aggravate them. In addition, many of these changes may occur even in the absence of strong demand for fuel efficiency, but possibly at a slower rate.

CAN WE HAVE A 75= MPG CAR?

There are no *technological* barriers to designing and building a four-passenger automobile that could achieve 75 mpg on the combined **55/45** percent highway/city EPA driving cycle. Such a car would take at least 5 years to design and develop and might be costly to manufacture, but it is technically feasible. It should be noted, of course, that the appearance of one or a few models that get 75 mpg would have little immediate effect on *fleet* average fuel economy, or on the Nation's petroleum consumption.

High fuel economy entails tradeoffs and compromises that affect other features of vehicle design–carrying capacity, performance, safety, comfort, and related amenities. Technology is a critical factor in managing these tradeoffs. Some routes to improved passenger car fuel economy also increase manufacturing costs (diesel engines, more complicated transmissions, lightweight materials). Here again, better technology can help to improve fuel economy at the least cost.

If a 75-mpg car can be made sufficiently attractive to consumers in terms of the other features beyond fuel economy that affect purchasing decisions—including price, but also the variety of less tangible factors that contribute to perceived value—then automakers will build such cars, confi-

dent that they will find a market. The interplay between consumer demand and automotive technology will determine when 75-mpg cars will appear. Consumer expectations concerning fuel costs and the possibility of future shortages of fuel, as well as their judgments of the practicality of such cars, will be important factors affecting the rate at which these cars would be introduced.

An automobile designed to achieve 75 mpg might look much like a current subcompact—e.g., a General Motors Chevette—but, as discussed in chapter 5, would be considerably different under the skin. It would have to be lighter, and might also be somewhat smaller—with a curb weight of perhaps 1,600 lb as opposed to about **2,000** lb for the Chevette. The actual weight depends not only on the size of the car, but also on the materials from which it is made. By using materials with high strength-to-weight ratios wherever possible—or, where strength or stiffness are not important, materials of low density—a four-passenger car could weigh, in principle, even less than the 1,600 lb suggested above. Costs are the limiting factors in the use of such materials—both the costs of the materials themselves and the costs of the required manufacturing processes.
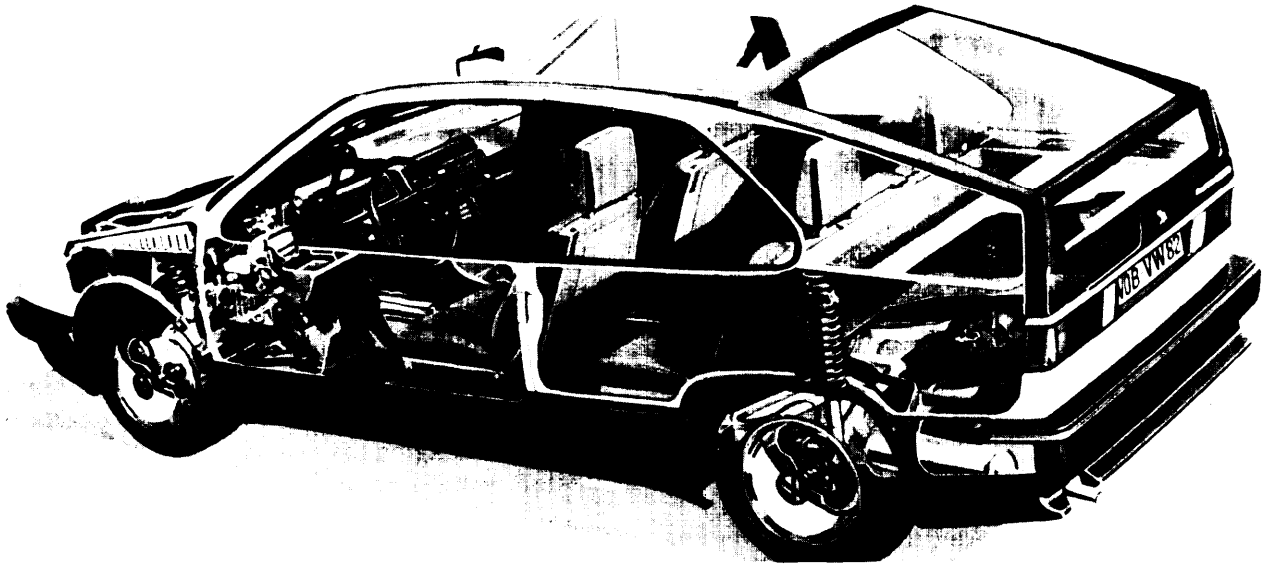
Artists drawing of the VW2000, a three-cylinder diesel test vehicle that has achieved over 60 mpg in standard fuel-efficiency tests

The other essential element in a 75-mpg car is an efficient powertrain. For a car weighing 1,600 lb or less, a relatively small diesel engine–one with a displacement in the range of 0.9 to 1.3 liters–would suffice. The transmission could be either a manual design or a considerably improved automatic, perhaps a continuously variable transmission.

To get 75 mpg would also require a great deal of attention to the detailed design of many aspects of the car—low aerodynamic drag, low rolling resistance, use of microprocessor controls, minimal accessories, and parasitic loads—with careful engineering development throughout the vehicle system. None of this depends on technological breakthroughs.

Given equally good design practices, the resulting car would not be as safe as a larger vehicle. Nor would it be luxurious. It might not have air conditioning. It would probably not be able to pull a camping trailer through the Rocky Mountains. But it could *get 75* mpg. When automobile manufacturers—here, in Europe, and in Japan—decide that American consumers want such a car, they will build it.

ARE SMALL CARS LESS SAFE THAN LARGE CARS?

One of the easiest ways to increase the fuel economy of passenger cars is to make them lighter. Although it is possible to make cars somewhat lighter without making them smaller, in general size and weight go together. Thus, cars with increased fuel economy are typically smaller—a downward trend in the size and weight of cars sold in the U.S. market began in 1977 and will continue through the 1980's, although gradually leveling off.

Size is the more critical variable for safety, although weight also affects the dynamics of collisions. *A great deal of improvement in the safety of cars of all sizes is possible through improved design–but given best practice design, a big car will always be safer than a small car in a collision.* As a result, making cars smaller to improve fuel economy will, everything else being equal, increase risks to drivers and passengers. Assuming no change in the way the cars are driven, there will be more injuries and fatalities than would occur with bigger cars embodying equivalent design practices and having identical accident avoidance capabilities.

Size affects safety because when an automobile hits another object–whether another car, a truck, or a roadside obstacle—the car itself slows, or is decelerated (the "first collision"), and the occupants must then be slowed with respect to the vehicle (the "second collision"). To minimize the chance of injury, the decelerations of the occupants with respect to the passenger compartment during the second collision must be minimized, The occupants must also be protected against intrusion or penetration of the passenger compartment from the outside. But controlling decelerations during the second collision depends on the deceleration of the entire vehicle during the first collision. Given good design practices, the severity of both the first and the second collision can be lowered, on the average, if the car is made larger.

Ideally, the vehicle structure will deform in a controlled manner around the passenger compartment during a collision, so that the average deceleration of the passenger compartment in the first collision will be low. The larger the car, the more space the designer can utilize to manage the deformations and decelerations—e.g., by using a crushable front-end. In a small car, there is less room for controlled deformation without intruding on the passenger compartment. Within the passenger compartment, more space means more room to control the deceleration of the passengers—using belts, harnesses, padding, and other measures—with less risk of hitting unyielding portions of the vehicle structure. More room also makes penetration or other breaches of the integrity of the compartment less likely. One pathway to increased fuel economy without sacrificing collision protection is therefore to make cars lighter by design changes and/or different materials while preserving as much space as possible for managing the energies that must be dissipated in the first and second collisions.

Because vehicle size and weight are not the only significant factors in determining vehicle safety, and because "all other things being equal" does not apply in actual real-world situations, any conclusion about the relative safety of large and small cars should be tempered with the following observations:

1. The recent series of crash tests sponsored by the National Highway Traffic Safety Administration demonstrated that vehicles of approximately equal size can offer remarkably different degrees of crash protection to their occupants. In many cases, differences between cars of equal size overshadowed differences between size classes in the kind of accident tested (35-mph collision head-on into a barrier).
2. Crash-avoidance capabilities of large and small cars are unlikely to be the same, and any differences must be factored into an evaluation of relative safety. Unfortunately, the effects of differences in such capabilities are difficult to measure because they represent both physical differences in the vehicles and driver responses to those differences.
3. Available traffic safety data and analysis is often confusing and ambiguous on the subject of large car/small car safety differences.

Although analyses of car-to-car crashes tend to agree that occupants of large cars are at a lesser risk than those of smaller cars, there is no such firm agreement about the other classes of accidents that account for three-quarters of all passenger vehicle occupant fatalities. A probable reason for the ambiguity of results is the shortage of consistent, nationwide data on accident incidence and de-tails; only fatal accidents are widely recorded. Another reason is the multitude of factors other than car size that might affect injury and fatality rates. Important factors include differences (among different size classes) in driver and occupant age distribution, general types of trips taken, average annual mileage, vehicle age distribution, and seatbelt usage.

HOW STRONG IS CURRENT DEMAND FOR FUEL EFFICIENCY IN CARS?

An extremely important factor influencing future new-car average fuel efficiency is the market demand for this attribute, relative to the other features the new-car buyer wants. Although it is, at best, only an approximate measure of future market behavior, examination of recent demand patterns in the new-car market can provide some insights about current demand for fuel efficiency. I n particular, the importance of fuel efficiency as compared with car size, price, and performance is examined for 1981 model gasoline-fueled cars* sold through January 5, 1981.

Table 17 presents a compari son of the average fuel efficiency of new gasoline-fueled 1981 model cars sold through January 5, 1981, with the fuel efficiency of the most efficient car in each of the Environmental Protection Agency's (EPA) nine size classes. Also shown are the sales fractions and the nationality of the manufacturer of the most efficient vehicle, These data show that the average fuel efficiency of new cars sold was 25 mpg, but if consumers had bought only the most fuel-efficient car in each size class* (and manufacturers had been able to supply this demand),

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*The results of the analysis would change somewhat if diesels were included, primarily with respect to nationality of manufacturers because U.S. manufacturers did not offer diesels in several size classes in 1981. U.S. manufacturers, however, are beginning to offer diesels in most size categories; but the relevant data are not now available. In 1981, about 95 percent of the automobiles sold were gasoline-powered.

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*Interestingly, this would also have resulted in U.S. manufacturers and captive imports capturing over 90 percent of sales, rather than 74 percent of sales that they actually achieved in this period. If diesels are included, however, average fuel efficiency could have been slightly higher than 33 mpg, but less than 60 percent of the cars purchased would be domestically produced.

Table 17.—Comparison of Average and Highest Fuel Efficiency for 1981 Model Gasoline-Fueied Cars in Each Size Class

EPA size class	Sales fraction (percent)	Sales-weighted average fuel efficiency of cars sold through Jan. 5, 1981 (mpg)	Fuel efficiency of most fuel-efficient model in size class (mpg)	Nationality of manufacturer of most fuel-efficient model
Two-seater.............	2	22	30	Italian
Minicompact	3	34	45	Japanese
Subcompact	30	28	42	United States (Captive Import)
Compact	9	27	37	United States
Midsize	37	23	31	United States
Large	9		24	United States
Small wagon	4	30	37	Japanese
Midsize wagon	5	23	30	United States
Large wagon	1	18	20	United States
Sales-weighted average		25	33	

SOURCE: Data from J. A, Foster, J. D. Murrell, and S. L. Loos, US. Environmental Protection Agency, "Light Duty Automotive Fuel Economy . . Trends Through 1981," SAE papar No. 810388, February 1981.

the **average fuel efficiency would** have been 33 mpg (a 33 percent increase). Because EPA's size classes are based on cars' interior volume, it is clear that demand for large interior volume in cars is not currently preventing a significantly higher average fuel efficiency in new cars than is actually being purchased.

Similarly, a comparison of prices shows that the most fuel-efficient 1981 model cars generally had a base sticker price in the middle or lower half of the price range of cars in each size classification. * Thus, there is no evidence that price is constraining the purchase of fuel-efficient cars either.

A further comparison of the average and most fuel-efficient cars in each size category shows that the average cars are heavier and have more powerful engines than the most fuel-efficient models. However, OTA's analysis indicates that the greater engine power found in the average car sold is, to a large extent, needed simply because the car is heavier.** There is no indication that the

most fuel-efficient car in most size categories performs (e.g., accelerates) significantly worse than the averge 1981 model car actually sold in that category. Although there are exceptions to this in certain size categories (e.g., two-seaters, large cars, and possibly midsized station wagons), these exceptions account for only about 10 to 15 percent of total sales.

This analysis indicates that interior volume, price, and performance cannot account for the large difference between the fuel efficiency of cars actually sold and what was available. As in' the past, consumers consider features such as style, quality, safety, ability to carry or haul heavier loads, and energy-intensive accessories to be of comparable importance to fuel economy. It is probable, therefore, that new-car average fuel efficiency could be significantly increased if consumer demand for fuel economy were strengthened.

"Sales-weighted average sticker prices for comparably equipped cars are not currently available.

**For example, in subcompacts and midsized cars (accounting together for 67 percent of sales), the average car weighed about 33 percent more and had about 50 percent larger engine displacement (which is correlated to power) than the most fuel-efficient car. A further comparison of specific fuel efficiency (ton miles per gallon, or the mpg of an equivalent car weighing 1 ton) shows that, for midsized cars (37 percent of sales), the difference in fuel efficiency between the average and the most fuel-efficient car can be explained solely on the basis of weight. Thus, there is no indication that the average car has better performance characteristics (e.g., acceleration) than does the most fuel-efficient model. A similar comparison of subcompacts indicates that, if anything, one would expect the most fuel-efficient model to perform better than the average.

WHAT ARE THE PROSPECTS FOR ELECTRIC VEHICLES?

EVs were among the first cars built, but they had almost vanished from the marketplace by the 1920's, **primarily because they could not compete with gasoline-powered vehicles in terms of price and performance. Due to concern over automobile emissions, the increasing price** of oil and recent oil supply disruptions, however, there has been a renewed interest in this technology. The advantages of EVs are that they derive their energy from reliable supplies of electricity, which can be produced from abundant domestic energy sources, and they operate without exhaust emissions. Their disadvantages are their high cost and poor performance and the increased sulfur dioxide emissions that result from increased electric generation.

From the consumer's point of view, the problems with EVs are principally centered on battery technology. Current batteries are expensive and heavy, relative to the energy they store; they require several hours to recharge; and they must be replaced approximately every 10,000 miles at a cost of $1,500 to $3,000. The weight of batteries limits vehicle range, * performance, and cargo- and passenger-carrying capacity. Because of the cost of batteries and electric controls, a new EV is estimated to cost about $3,000 more than a comparable gasoline-powered vehicle. And replacing batteries every 10,000 miles because of limited life would add more than $().10/mile to

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*Usually 100 miles or less between recharging.

operating costs, which is equivalent to gasoline costing more than $4 to $6/gal for a 40- to 60-mpg car.

Future developments in battery technology could improve the prospects for EVs, and several approaches are being pursued. But the understanding of battery technology is not adequate to predict if or when significant improvements will occur.

If battery problems persist, sales of EVs could be limited to a relatively few people and firms that can afford to pay a premium to avoid transportation problems that would arise if liquid fuel supplies were disrupted. On the other hand, if gasoline prices increase by more than a factor of four or five or if gasoline and diesel fuel are rationed at levels too low to satisfy driving needs even with the most fuel-efficient cars, then EVs could be favored—provided electricity prices do not also increase dramatically.

Prospects for EVs may also be influenced by Government incentives based on national and regional considerations. One such consideration is the oil displacement potential of EVs. EVs are most nearly a substitute for small cars, which are likely to be relatively fuel efficient in the 1990's; but the limited range of current and near-term EVs prevents them from being a substitute for all of the yearly travel needs supplied by a small gasoline-driven car. As a result, oil displacement by EVs is likely to be relatively small; probably no more than 0.1 million barrels per day (MMB/D) with a 10-percent market penetration, even assuming no oil consumption by those electric utilities supplying electricity to EVs.

At current levels of utility oil consumption, however, the net oil displacement would be less than 0.1 MMB/D (see ch. **5** for details). Future reductions in utility oil consumption will improve the oil displacement potential of EVs, while increased fuel efficiency in petroleum-fueled cars will reduce any advantage EVs might have in this connection.

A final consideration is the reduced automotive emissions and other environmental effects of EV use. Because that use would be concentrated in urban areas and the necessary increased electric power generation would be well outside of these areas, cities with oxidant problems that replace large numbers of conventional vehicles with EVs will significantly improve their air quality. This incentive could improve the prospects for EV sales and use. Emissions and other impacts of increased power generation may cancel some of this benefit, but the positive urban effects are likely to be considered the most important environmental attributes of EVs.

IF A LARGE-SCALE SYNFUELS INDUSTRY IS BUILT . . . WILL PUBLIC AND WORKER HEALTH AND SAFETY AS WELL AS THE ENVIRONMENT BE ADEQUATELY PROTECTED?

It is virtually a truism that all systems designed to produce large amounts of energy will have the *potential to* adversely affect the environment and human health and safety. It is equally true that, with few exceptions, it is technically feasible to reduce these effects to the point where they are generally considered an acceptable exchange for the energy benefits that will be obtained. In current arguments concerning synthetic fuels development, as with many other such arguments, the environmental community has focused on the potential damaging effects, while the industry has focused on the controls and environmental management procedures available to them. Gaining a perspective on the correct balance between these two points of view—on the likelihood that some of the potential damages will *actually occur* —is especially important in the case of synfuels development because environmental dangers have become a genuine public concern.

As shown in the evaluation of potential environmental impacts in this report, many of the important impacts of a large synfuels industry will be similar in kind to those of coal-fired electric power generation. The magnitude of these impacts (acid drainage and land subsidence from coal mines, emissions of sulfur and nitrogen oxides and particulate, effects of water use, population increases, etc.) is likely to be similar to and in some cases less than the likely impacts of the new, tightly controlled electric-generating capacity projected to be installed in the same time frame.

A second set of impacts–those associated with the toxic materials present in the process and waste streams of the plants and possibly in their products—are not predictable at this time but are, nevertheless, very worrisome. Factors that should be useful in gaging the risk from these impacts include the technical problems facing the designers of environmental controls, the availability of adequate regulations and regulatory agency resources, past industry and Government behavior in implementing environmental and safety controls, and difficulties that might be encountered in detecting adverse impacts and tracing them to their sources. A brief discussion of these factors follows:

1. *Technical* Problems.—Virtually all the controls which are planned for synthetic fuels plants are based on present engineering practices in the petroleum refining, petrochemical, coal-tar processing and power generation industries, and industry spokesmen appear confident that they will work satisfactorily. Problems may be encountered, however, because of differences between these industries and synfuels plants—the latter have higher concentrations of toxic hydrocarbons and trace metals, higher pressures, and more erosive process streams, in particular, As yet, few effluent streams have been sent through integrated control systems, so it has not yet been demonstrated that the various control processes will work satisfactorily in concert, Technical personnel at the Environmental Protection Agency (EPA) and the Department of Energy (DOE) have expressed particular concerns about control-system reliability.

Judging from these indications, it appears possible that a considerable period of time– possibly even a few years–will be necessary to solve control problems in the first few plants and get the environmental systems working with adequate performance and reliability. Delays are especially likely for direct-liquefaction plants, which have some particularly difficult problems involving toxic substances and erosive process streams. These delays may be aggravated by a potential gap in control technology development. Recent Federal policy has left the development of environmental controls largely to industry. The major concern of the synfuels industry, on the other hand, is to clean up waste streams so that existing regulations may be met. Less emphasis is placed on controlling pollutants such as polynuclear aromatics that are not currently regulated. It appears certain that there will be considerable pressure to regulate these and other pollutants, but it is not certain that the industry will be able to respond quickly to such regulations.

2. *Detecting and Tracing Impacts.* —One of the major potential dangers of synfuels plants will be low-level emissions of toxic substances, especially through vapor leaks (primary danger to workers) or ground water contamination from waste disposal (primary danger to the public and the general environment), Current ground water monitoring probably is inadequate to provide a desirable margin of safety, although presumably knowledge of this danger will result in better monitoring systems. A major problem may be the long lag times associated with detecting carcinogenic/mutagenic/teratogenic damages—a major concern associated with trace hydrocarbons produced under the physical and chemical conditions present in most synfuels reactors.

3. *Regulation.* –The regulatory climate facing an emerging synfuels industry is mixed. On the one hand, ambient standards for particulates, sulfur oxides, and other pollutants

associated with conventional combustion sources are in place and should offer adequate protection to public health with respect to this group of pollutants. A limited number of other standards, including those for drinking water protection, also are in place. On the other hand, new source performance standards–federally set emission standards—have not been determined yet, nor have national emission standards for hazardous air pollutants been set for the variety of fugitive hydrocarbons or vaporized trace elements that might escape from synfuels plants. Likewise, although Occupational Safety and Health Administration (OSHA) exposure standards and workplace safety requirements do apply to several chemicals known or expected to occur in synfuels production, the majority of such chemicals are not regulated at this time.

These regulatory gaps are not surprising, given the limited experience with synfuels plants, and several of the standards–especially the emissions standards—probably could not have been properly set at this stage of industry development even had there been intensive environmental research. However, the difficulties in detecting impacts described above, and some doubts as to the availability of environmental research resources at the Federal level, lead to concern about the adequacy of future regulation.

4. Past History. –Given both the potential for environmental harm and the potential for mitigating measures, the attitude and behavior of both the industries that will build and operate synfuels plants and the agencies that will regulate them are critical determinants of actual environmental risk. Consequently, an understanding of the past environmental record of these entities should be a useful guide in gaging this risk. Unfortunately, there is little in the way of comprehensive research on this behavior. Even the compilation of data on compliance with existing regulations and incidence of deaths and injuries is quite weak.

For example, to our knowledge EPA has sponsored only one major evaluation of compliance with emission regulations; this recent study of nine States showed that 70 percent of all sources failed to comply fully with those regulations. Also, Department of Labor statistics on occupational hazards are compiled in such a way as to overlook health problems that cannot easily be attributed to a specific cause—just the kinds of problems of most concern to an evaluation of potential synfuels problems. Consequently, occupational health and safety statistics that appear favorable to synfuels-related industries are likely to be an inadequate guide to the actual hazard potential.

Anecdotal evidence, although not an adequate basis for evaluating risk, may be useful as a warning signal of future causes of health and safety problems. For example, recent studies have demonstrated that protective gloves used in the chemical industry fail to protect workers from several hazardous, and commonly encountered, chemicals. This points to both an immediate technical problem and an institutional failure in the chemical industry itself and its regulating agencies. On the other hand, the tests, which were sponsored by OSHA, also demonstrate the ability of the regulatory agency to correct past failures.

Another example of anecdotal evidence that may indicate some future problems with industry performance is that some developers have failed to incorporate separate and measurable control systems in synfuels pilot plants. For example, a direct-liquefaction facility in Texas has its effluents mixed with those of a neighboring refinery, rather than having a separate control system whose effectiveness at treating synfuels wastes can be tested and optimized. This might reflect industry's lack of priority or, more likely, its high level of confidence that no unusual control problems will arise that cannot be readily handled at the commercial stage. There is considerable disagreement about the validity of this confidence.

Finally, there is ample evidence that the chemical industry and its regulators have had significant problems in dealing properly with subtle, slow-acting chemical poisons. Chemicals that were unregulated or inadequately regulated for long periods of time, and whose subsequent regulation became major sources of conflict between industry and Government, include benzene, formaldehyde, vinyl chloride, tetraethyl lead, the pesticide 2,4,5-T, and many others. In some cases, controversy persists despite years or even decades of research.

An implication of the above discussion is that adequate environmental management of synfuels is unlikely to occur automatically when development begins in earnest. Although OTA believes that the various waste streams can be adequately controlled, this is going to require a strong industry effort to determine the full range of potential environmental impacts associated with devel-

opment and to devise and implement measures to mitigate or prevent the important impacts. At present, however, there are indications that most developers are interested primarily in meeting current regulatory requirements, most of which are limited in their coverage of potential impacts. And completing the regulatory record, to provide the incentive necessary to stimulate further environmental efforts, is going to be a difficult and time-consuming job, particularly if ongoing cutbacks in Government research and regulatory budgets are not accompanied by promised improvements in efficiency.

Finally, there are some remaining doubts about the reliability of proposed control systems in meeting current regulatory requirements. These potential problem areas imply that congressional oversight of an emerging synfuels industry will need to be especially vigorous in its coverage of environmental concerns.

WILL WATER SUPPLY CONSTRAIN SYNFUELS DEVELOPMENT?

In the aggregate, the water consumption requirements for synfuels development are small. Achieving a synfuels production capability of 2 million barrels per day oil equivalent would require on the order of 0.3 million acre-feet/year or about 0.2 percent of estimated total current national freshwater consumption, Nevertheless, synfuels plants are individually large water consumers. Depending on both the water supply sources chosen for synfuels development and the size and timing of water demands from other users, synfuels development could create conflicts among users for increasingly scarce water supplies or exacerbate conflicts in areas that are already water-short.

The nature and extent of the impacts of synfuels development on water availability are controversial. The controversy arises in large part because of the many hydrologic as well as institutional, legal, political, and economic uncertainties and constraints which underlie the data, and because of varying assumptions and assessment methodologies used. The importance of the fac-

tors influencing water availability will vary in the different river basins where the energy resources are located.

In the major Eastern river basins where energy resources are located (i.e., the Ohio, Tennessee, and the Upper Mississippi), water should generally be adequate on the mainstems and larger tributaries, without new storage, to support likely synfuels development. However, localized water scarcity problems could arise during the inevitable dry periods or due to development on smaller tributaries. The severity of these local problems cannot be ascertained from existing data and they have not yet been examined systematically. With appropriate water planning and management, it should be possible to reduce, if not eliminate, any local problems that might arise.

Competition for water in the West already exists and is expected to intensify with or without synfuels development. In the Missouri River Basin, the magnitude of the institutional, legal, and political uncertainties, together with the need

for major new water storage projects to average-out seasonal and yearly streamflow variations, preclude an unqualified conclusion as to the availability of water for synfuels development. The major sources of these uncertainties, which are difficult to quantify because of a lack of supporting information, include Federal reserve water rights (including Indian water rights claims), provisions of existing compacts, and instream flow reservations.

In the Upper Colorado River Basin, water could be made available to support the level of synfuels development expected over the next decade. However, the institutional, political, and legal uncertainties make it difficult to determine which sources would be used and the actual amount of water that would be made available from these sources. The principal uncertainties concern the use of Federal storage, the transfer of water rights, provisions of existing compacts and treaties, and Federal reserve rights. The range of uncertainty surrounding the water availability to the entire basin after 1990 is so broad that it tends to subsume the amount of water that would be needed for expanded synfuels development.

ARE SYNTHETIC FUELS COMPATIBLE WITH EXISTING END USES?

When introducing new fuels into the U.S. liquid fuels system, it is important to determine the compatibility of the new fuels with existing end uses in order to determine what end-use changes, if any, may be necessary. In this section the compatibility of various synfuels with transportation end uses is briefly described.

Alcohols

Neither pure ethanol nor pure methanol can be used in existing automobiles without modifying the fuel delivery system, but cars using them can be readily built and engines optimized for pure alcohol use would probably be 10 to 20 percent more efficient than their gasoline counterparts. New cars currently are being built to be compatible with gasohol (1 O percent ethanol, 90 percent gasoline), so potential problems with this blend are likely to disappear with time.[8] Methanol-gasoline blends have been tested with mixed results. Principal problems include increased evaporative emissions and phase separation of the fuel in the presence of small amounts of water. These problems can be reduced by blending t-butanol (another alcohol) with the methanol, and such a blend is currently being tested.[9] However, due to the corrosive effects of methanol on

some plastics, rubbers, and metals in some vehicles, it probably is preferable to use methanol in its pure form in modified vehicles or to require that components in new automobiles be compatible with methanol blends.

Shale Oil

Shale oil has been successfully refined at the pilot plant level to products that meet refinery specifications for petroleum derived gasoline, diesel fuel, and jet fuel.[10] The properties of the diesel and jet fuels are shown in tables 18 and 19, where they are compared with the petroleum counterparts. Current indications are that the major question with respect to compatibility of these fuels with their end uses is what minimum level of refining (and thus refining cost) will be needed to satisfy the needs of end users.

Direct Coal Liquids

One of the direct coal liquids, SRC II, has also been successfully refined to products that meet refinery specifications for gasoline and jet fuel (tables 18 and 19). (The cetane number of the resultant "diesel fuel, " however, is lower than that normally required for petroleum diesel fuel.) The gasoline, because of its aromatics content,

[8]*Energy From Biological Processes, Volume II: Technical and Environmental Analyses,* **OTA-E-1 28 (Washington, D. C.: U.S. Congress, Office of Technology Assessment, September 1980).**
[9]Ibid.

[10]**R. A. Sullivan and H. A.** Frumkin, **"Refining and Upgrading of** Synfuels **From Coal and Oil Shales by Advanced Catalytic Processes, " third interim report, prepared for DOE under contract No.** EF-76-C-01-2315, **Chevron Research Co., Apr. 30, 1980.**

Table 18.–Properties of Selected Jet Fuels Derived From Shale Oil and SRC-II

	Typical petroleum (Jet A)	350° to 500° F hydrotreated shale oil	300° to 535° F hydrocracked shale oil	300° to 550° F or 250° to 570° F hydrotreated SRC-11
Gravity, 'API	37-51	42	47	33-36
Group type, LV%:				
Paraffins.		35	55	3-4
Cycloparaffins.		45	40	93-81
Aromatics	<20	20	5	4-15
Smoke points, mm.	> 20	21	35	20-23
Freeze point, °F	−40	−42	−65	−75 to −95
Nitrogen.	(a)	2	0.1	0.1

[a] In addition, severe stability requirements mean that heteroatom content must be very low(usually the nitrogen content is less than 10 ppm for petroleum-derived jet fuel).

SOURCE: R. A. Sullivan and H. A. Frumkin, "Refining and Upgrading of Synfuels From Coal and Oil Shales by Advanced Catalytic Processes," third interim report, prepared for DOE under contract No.EF-76-C-01-2315, Chevron Research Co., Apr. 30, 1980.

Table 19.–Properties of Selected Diesal Fuels Derived From Shale Oil and SRC-II

	Typical petroleum	350° to 650° F hydrotreated shale oil	350° to 600° F hydrotreated shale oil coker distillate	350° F+ hydrotreated SRC-II
Gravity, API	>30	38	41	29
Cetane No.	>40	46[a]	48	39
Pour point, °F. . .	<+ 15	− 5	−20	−55
Group type, LV%:				
P		37	41	−4-7
N		44	41	70-93
A		19	18	2-23
Nitrogen, ppm[b] . .	(b)	350	350	0.1-0.5

[a] Estimated.
[b] Heteroatoms must be removed to level required for stability (usually 500 ppm N for petroleum).

SOURCE: R. A. Sullivan and H. A. Frumkin, "Refining and Upgrading of Synfuels From Coal and Oil Shales by Advanced Catalytic Processes, " third interim report, prepared for DOE under contract No. EF-76-C-01-2315, Chevron Research Co., Apr. 30, 1960.

would be used as an octane-enhancing blending agent in conventional gasoline. Aromatics, such as benzene and toluene, are currently used for this purpose in gasoline. Again, a principal question is what minimum level of refining will be needed. other direct coal liquids probably are similar to SRC Ii liquids.

Indirect Coal Liquids

Other than methanol, which was considered above, the principal indirect coal liquids for ground transportation are gasolines, although the Fischer-Tropsch (FT) processes can be arranged to produce a variety of distillate fuels, as well. There are no indications that these gasolines would not be compatible with the existing automobile fleet, either alone or in blends with conventional gasoline.

Caveat

Despite the apparent compatibility of hydrocarbon synfuels with existing end uses, refinery specifications do not uniquely determine all of the properties of the fuel. The tests used to characterize hydrocarbon fuels were designed for petroleum products and may be inadequate indicators for the synfuels. Some potential problems with the hydrocarbon synfuels that have been mentioned include:

- *Lubrication.* –Hydrotreating of synfuels is necessary to meet refinery specifications. However, the lubricating properties of the synfuels drop with this hydrotreating. This drop in lubricity could lead to possible problems with fuel-injection nozzles and other moving parts that rely on the fuel for lubrication.

● *Emissions.* —The particulate and nitrogen oxide emissions of synthetic diesel fuel could be greater than those from an otherwise comparable petroleum diesel fuel. Automobile manufacturers are having difficulty meeting emissions standards with conventional diesel fuel, and there is some concern that synfuels could aggravate these problems.

● *Variability.* —The direct liquefaction synfuels from coal can vary in composition depending on the coal used.11 Consequently, although the synfuel from one coal may be compatible with an end use, the same process might produce an incompatible synfuel if another coal is used.

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[1] **Ibid,**

In principle, if the exact chemical composition of synfuels were known, synfuels could be blended from petrochemicals and tested extensively for these potential problems before synfuels plants were built. In practice, however, the chemical compositions are so complex, varied, and process-dependent that this option is probably not practical.

The alternative is to wait until sufficient quantities of synfuels are available and to conduct extensive field tests of synfuels processed in various ways and from different coals. Until this is done, statements about the compatibility of hydrocarbon synfuels with current end uses are somewhat speculative.

Increased Automobile Fuel Efficiency

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Increased Automobile Fuel Efficiency

STATUS AND TRENDS

Until the 1970's, fuel economy was seldom important to American car buyers. Gasoline was cheap and plentiful, taxes on fuel and on car size low. In contrast with automobile markets in most of the rest of the world, automakers had few incentives to build small cars, or consumers to purchase them. The typical American passenger car –large, comfortable, durable–evolved in relative isolation from design trends and markets in other parts of the world. Fuel economy was a minor consideration. (This was not the case for heavy trucks, where fuel costs have always been a substantial component of operating expenses.)

In the late 1960's and early 1970's, Federal emissions control standards worked at the expense of fuel economy. But fuel economy pressures were also building—signified by gasoline shortages, the sudden rise in oil prices, and the passage of the Energy Policy and Conservation Act of 1975 (EPCA). EPCA set fleet average mileage standards for automobiles sold in the United States beginning in 1978. The combination of Corporate Average Fuel Economy (CAFE) standards and market forces stimulated rapid changes in the design of American cars, followed by a sharp **swing** in consumer demand during 1979 and 1980 toward small, economical imports.

A similar upsurge in small-car demand had followed the 1973-74 oil shock. Over the 1965-75 period, American-made cars averaged about 14 to 15 miles per gallon (mpg). * For model year 1980, the average for cars sold in the domestic market was up to 21 mpg, 1 mpg above the EPCA requirement. For 1981 models, domestic cars sold through January 5, 1981, averaged almost 24 mpg, or almost 2 mpg above EPCA requirements. (See also fig. 6.)

Most of the increases in fuel economy have come from downsizing—redesigning passenger cars so that they are smaller and lighter, and can use engines of lower horsepower. Other changes

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*Based on EPA's combined test cycles (55 percent city and 45 percent highway cycle).

Figure 6.—Historical Average New-Car Fuel Efficiency of Cars Sold in the United States
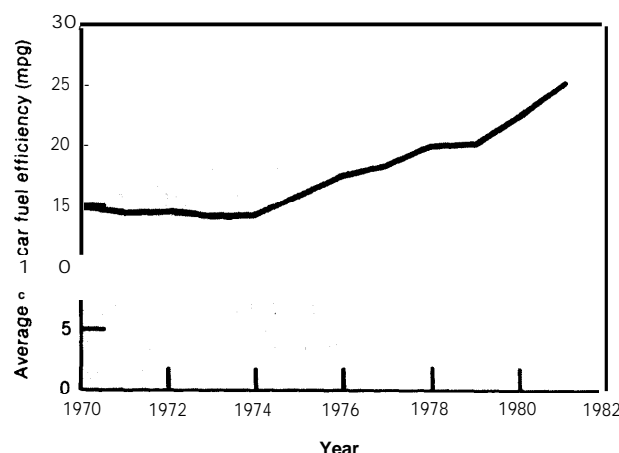
SOURCE: J. A. Foster, J. D. Murrell, and S. L. Loas, "Light Duty Automotive Fuel Economy. . Trends Through 1981 ," SAE Paper 810386, February 1981.

in vehicle designee. g., decreased aerodynamic drag and rolling resistance, improved automatic transmissions and higher rear axle ratios, electronic engine controls, greater penetration of diesels–have also helped to reduce fuel consumption.

While the latest technology is used in these redesigns, technology itself is not–and has not been–a limiting factor in passenger-car fuel economy in any fundamental sense. The limiting factor is what the manufacturers decide to build based on judgments of future consumer demand. Decisions on new models may also be constrained by the costs of new capital investment. Technology does have a vital role in managing the many tradeoffs among manufacturing and investment costs, fuel economy, and the other attributes that affect consumer preferences—quality, comfort, carrying capacity, drivability, and performance. Technology is also critical in managing possible tradeoffs involving fuel economy, emissions, and safety.

American automakers are still incrementally downsizing their fleets–in the process convert-

ing to front-wheel drive, which helps to preserve interior space. These redesigns have been largely paced by three interrelated factors: 1) CAFE standards, which require fleet averages of 27.5 mpg by 1985; 2) each manufacturer's estimates of future market demand in the various size classes (until 1979, market demand for smaller, more fuel-efficient cars lagged behind the CAFE standards, but it has now outstripped them—several recent projections point toward fleet averages of more than 30 mpg by 1985[1]); and, 3) the capital resources of U.S. firms, which affect both their ability to design and develop new small cars and their ability to invest in new plant and equipment for manufacturing them.

The gradual downsizing of the U.S. automobile fleet has been accompanied by an intensive developmental effort aimed at maximizing the fuel economy of cars of a given size, consistent with the need for low pollutant emission levels and occupant safety—both also matters of Government policy. Foreign manufacturers, who in 1980 accounted for about one-quarter of sales in the United States, are also improving the fuel economy of their fleets, but they can concentrate on technical improvements rather than new small-car designs because their product lines are already heavily oriented toward cars that are small in size and low in weight.

Because the U.S. automobile fleet now contains over 100 million cars, increases in new-car fuel economy take time to be felt. Typically, about half the cars of a given model year are still on the road after 10 years; it takes about 17 years before 99 percent are retired. Thus, while new-car fuel economy for the 1980 model year reached about 21 mpg, the average for the U.S. fleet in 1981 is still only about 16 to 17 mpg, a legacy of the big cars of earlier years. if new cars average 30 to 35 mpg by 1985—a target that is easily attainable from a technological standpoint–the average fuel efficiency of cars on the road would reach only about 22 mpg by 1985. While more than half the annual fuel savings asso-

ciated with the 1985 CAFE standards will be achieved by 1985, the full benefit of the 30-mpg new cars of 1985—and of further improvements in later years—will not come until the end of the century.

Of course, 30-mpg CAFE standards are possible right now, and 50-mpg cars are currently being sold. Proportionately higher fuel economy figures will in principle be attainable in the future, as automotive technology progresses. But today only a portion of consumers want such vehicles— because fuel economy often comes at the expense of comfort, accommodations for passengers and luggage, performance, luxury, convenience features and accessories, and other attributes more commonly found in larger cars–and manufacturers try to plan their future product mix to appeal to a broad range of consumer tastes.

The sudden shift in market demand toward small, fuel-efficient cars in 1974-75, followed by a resurgence in large-car sales during 1976-78 and another wave of demand for fuel efficiency in 1979 and 1980, illustrates the unpredictable nature of consumer preferences. The 1979 market shift has outpaced the CAFE standards. The 27.5-mpg requirement set by EPCA for the 1985 model year remains in effect for subsequent years unless modified by Congress. If world oil prices again stabilize, and supply exceeds demand—as occurred through much of 1981 —the risks and uncertainties facing U.S. automakers could multiply, a particularly worrisome situation given their precarious financial situations and the large capital outlays necessary for redesign and retooling. Recently, American automakers have been reassessing their commitments to rapid downsizing and new small-car lines—both because of cash flow shortfalls and because of uncertainty over future market demand.[2]

The 14-mpg U.S. fleet average of 1975 is a useful baseline for estimating recent and near-term fuel savings resulting from the combination of EPCA standards and market forces. For the period 1975-85, OTA estimates that fuel economy in-

[1]W. G. Agnew, "Automobile Fuel Economy Improvement," General Motors Research Publication GMR-3493, November 1980; *The U.S. Automobile Industry, 1980: Report to the President From the Secretary of Transportation, DOT-P-1 O-81-O2*, January 1981. Independent estimates by OTA are similar.

[2]J.Holusha, "Detroit's Clouded Crystal Ball; Gasoline Glut Spurs Review of Small Cars," *New York Times*, July 28, 1981, p. DI; J.Holusha, "For G. M., a Fresh Look at Spending Strategy," *New York Times*, Nov. 10, 1981, p. D1.

creases in passenger cars alone will have saved slightly **more than 0.8 MMB/DOE (million barrels** per day, oil equivalent) on the average—much less in the earlier years, and about twice as much near the end of this 10-year period, Considering only passenger cars, the cumulative saving through 1985 will be approximately 3 billion barrels (bbl) of petroleum–about 75 percent of the total U.S. crude oil imports during 1979 and 1980. For the period 1985-95, by the end of which the average efficiency of all cars on the road should be **30** mpg or more, the daily savings would be at least 3 million barrels per day (MMB/D), giving an additional cumulative saving of at least 10 billion bbl compared with a 14-mpg fleet. Thus, for the 20-year period 1975-95, the total savings from increased passenger-car fuel economy would be over 13 billion bbl—equivalent to 8 years of crude oil imports or about 7 years of net petroleum imports at the 1981 rate.

These estimated reductions in petroleum consumption could be larger if fuel-economy improvements proceed faster than assumed. Fuel-economy improvements in trucks, particularly light and medium trucks, will also save significant amounts. Nonetheless, the U.S. passenger-car fleet would still consume 3.6 MMB/D in 1985 and 3 MMB/D in 1995–compared with 4.3 MMB/D in 1980—if the passenger-car fleet grows as expected and cars continue to be driven at the historical rate of 10,000 miles per year, on the average. If automobile travel is reduced, fuel consumption would be decreased proportionately.

The savings in petroleum consumption–which represent a direct benefit to consumers as well as an indirect benefit because of the expected improvement in the U.S. balance of payments—also carry costs. These will generally take the form of higher purchase prices for new cars, even though these cars will be smaller. Costs will be higher because the redesign and retooling for a downsized U.S. fleet requires capital spending at rates significantly higher than the historical average for American manufacturers. Increased capital spending—which, along with the sales slump of 1979-81, shares responsibility for the over $4 billion lost by U.S. automakers during 1980–is passed along at least in part to purchas-

ers. To the extent that competitive forces allow, importers will also raise prices even though their capital spending rates may not have gone up.

Many of the technological roads to improved fuel economy also carry higher direct manufacturing costs. A familiar example is the diesel engine—which, for comparable performance, can increase passenger car fuel economy, and decrease operating costs, by as much as 25 percent, but at a substantial penalty in purchase price. In this case, the higher costs stem largely from an intrinsically expensive fuel injection system, but also from the greater mechanical strength and bulk required in a diesel engine. Beyond economic costs and benefits, smaller cars cannot be designed to be as safe as larger cars (given best practice design in both) –thus, risks of death and injury in collisions could go up.

For the 10-year period 1968-77, average annual capital investment by the big three U.S. automakers in constant 1980 dollars was $6.68 billions (AMC and, in later years, Volkswagen of America add only small amounts to these averages). Over this period, production fluctuated considerably, but with only a slight upward trend; thus, the average expenditure is primarily that for normal redesign and retooling as new models are introduced and existing product lines updated, rather than for increases in production capacity. Note that the period 1968-77 includes investments associated with the introductions of several new small cars around 1970 (Pinto, Maverick, Vega), as well as later subcompact designs (Chevette, Omni/Horizon). The figures also include overseas investments by the three U.S. firms.

The 2 years with the highest investments during the 1968-77 period were 1970 ($7.67 billion) and 1977 ($7,78 billion). In 1978, investment rose to $9.21 billion, and in 1979 it reached $10.5 billion (still in 1980 dollars) –half again as much as the historical level. (See fig. 7.) Estimates of investment for the 5-year period 1980-84 reach close

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[3]These investment figures were tabulated from annual reports by R. A. Leone, W. J. Abernathy, S. P. Bradley, and J. A. Hunker, "Regulation and Technological Innovation in the Autombile Industry, " report to OTA under contract No. 933-3800.0, May 1980, pp. 2-92. Conversions to 1980 dollars are based on the implicit price deflator for nonresidential fixed domestic investment.

Figure 7.—Historical Capital Expenditures by U.S. Automobile Manufacturers
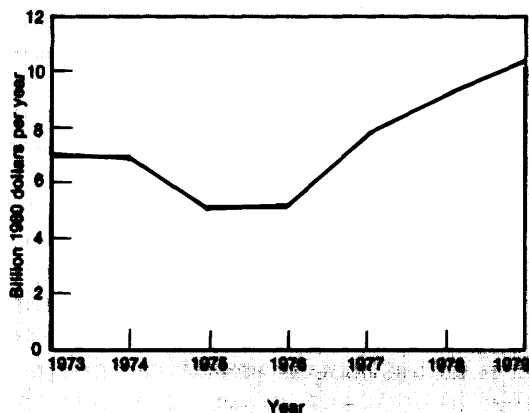
SOURCE: G. Kulp, D. B Shonka, and M. C. Holcomb, "Transportation Energy Conservation Data Book: Edition 5," Oak Ridge National Laboratory, ORNL-5765, November 1981.

to $60 billion.[45] Such estimates have generally been based on fleet redesigns to meet EPCA requirements through 1985. While it is doubtful that

[4]General Accounting Office, "Producing More Fuel-Efficient Automobiles: A Costly Proposition, " CED-82-14, Jan. 19, 1982.

'Fuel Economy Standards for New Passenger Cars After 1985 (Washington, D. C.: Congressional Budget Office, December 1980), p. 56. Other estimates are generally comparable but may differ as to whether development costs or only fixed investment are included.

they include much spending for new models to be introduced in the immediate post-1985 period, they do include substantial overseas expenditures —perhaps one-quarter or more.

The $60 billion estimate represents about $12 billion per year in 1980 dollars, nearly double the historical spending level. It is a clear indication of the market pressures (for smaller cars as well as for greater fuel economy in vehicles of all sizes, including light trucks) being placed on domestic manufacturers. Component suppliers also face higher-than-normal investments.

The remainder of this chapter treats the factors that determine automobile fuel consumption in more detail—both the technological factors and market demand—as well as the net savings in fuel consumption that may accrue from increases in automobile fuel economy. While consumer preferences—as judged by manufacturers in planning their future product lines–are dominant, technology is vital in maximizing the fuel economy that can be achieved by cars of given size and weight, as well as given levels of performance, emissions, and occupant safety.

AUTOMOBILE TECHNOLOGIES

Fuel consumed by an automobile (or truck) depends, first, on the work (or power) expended to move the vehicle (and its passengers and cargo), and second, on the efficiency with which the energy contained in the fuel (gasoline, diesel fuel) is converted to work. The power requirements depend, in essence, on: 1) the driving cycle– the pattern of acceleration, steady-state operation, coasting, and braking–which is affected by traffic and terrain, but otherwise controlled by the driver; 2) the weight and rolling resistance of the vehicle; and **3)** the aerodynamic drag, which depends on both the size and shape of the vehicle and is also a function of speed. The designer controls weight, aerodynamic drag, and to some extent the rolling resistance, but can affect the

driving cycle only indirectly –e.g., through the power output and gear ratios available to the driver.

The fuel consumed in producing the power to move a vehicle of given size and weight is again a function of vehicle design, primarily engine design. The efficiency with which the engine converts the energy in the fuel to useful work depends on the type of engine as well as its detail design; diesel engines are more efficient than spark-ignition (gasoline) engines, but not all diesel engines have the same efficiency.

Furthermore, an engine's efficiency varies with load. For example, when a car is idling at a traffic light, the engine's efficiency is virtually zero

because the energy in the fuel is being used only to overcome the internal friction of the engine and to power accessories. Engines are more efficient at relatively high loads (accelerating, driving fast, or climbing hills), but such operation will still use fuel at a high rate simply because the power demands are high–hence the justification for the 55-mph speed limit as an energy-conservation measure.

Efficiency–the fraction of the fuel energy that can be converted to useful work—cannot be 100 percent in a heat engine for both theoretical and practical reasons. For a typical automobile engine, peak efficiency may exceed 30 percent, but this is attained for only a single combination of load and speed. *Average* efficiencies, characteristic of normal driving, may be only 12 or 13 percent, even lower under cold-start and warmup operation. To illustrate this point, figure 8 shows energy losses for the drivetrain in one 1977 model car in the Environmental Protection Agency's (EPA) urban cycle. This figure should not be taken

too literally because losses vary considerably from car to car and numerous design changes have been implemented since 1977, but the figure does serve to illustrate approximate magnitudes.

The design of the engine affects the amount of fuel consumed during the driving cycle in two basic ways. First, the size of the engine fixes its maximum power output. In general, a smaller engine in a car of given size and weight will give better fuel economy, mainly because the smaller engine will, on the average, be operating more heavily loaded, hence in a more efficient part of its range, There are practical limits to engine downsizing, however, because a heavily loaded, underpowered engine provides poor performance and can suffer poor durability.

Second, the designer can directly affect driving-cycle fuel economy through the transmission and axle interposed between the engine and wheels. Significant gains in fuel economy over the past few years have come from decreases in rear axle

Figure 8.—Fuel Use in City Portion of EPA Fuel' Efficiency Test Cycle (2,750 lb/2.3 liter)
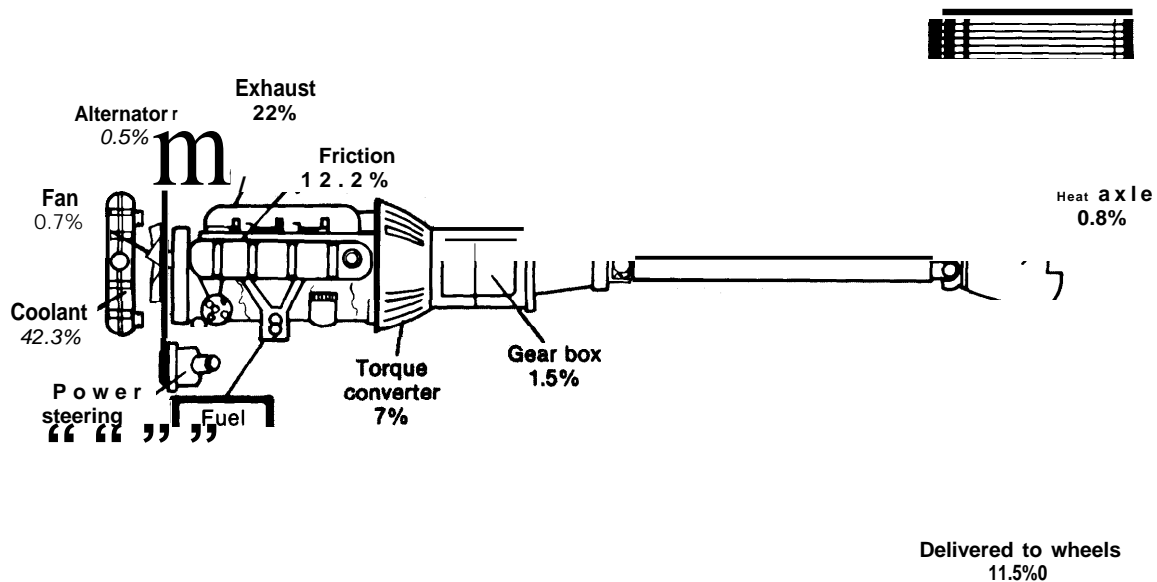
SOURCE Serge Gratch, Ford Motor Co., private communication, 1982.

ratios* so that engines are operating at higher efficiencies during highway operation, and from changes in transmission ratios** to better match driving needs to engine efficiency (in earlier years transmission ratios were often chosen to maximize performance rather than fuel economy). Adding more speeds to the transmission—whether manual or automatic—serves the same objective. The optimum would be a continuously variable, stepless transmission allowing the engine to operate at all times at high loads where its efficiency is greatest. (Such transmissions can be built today, but require further development for widespread use in cars.)

Changes in many other areas of automobile design can help increase fuel economy, but the primary factors are size (which is one of the factors that determines aerodynamic drag), weight (which determines the power needed for acceleration, as well as rolling resistance), and powertrain characteristics (engine plus transmission). These are discussed in more detail below, in the context of the driving cycle—itself a critical variable in fuel economy—followed by brief discussions of emissions and safety tradeoffs, methanol-fueled vehicles, and electric vehicles (EVs).

Vehicle Size and Weight

On a sales-averaged basis, the inertia weight of cars sold in the United States during 1976 (including imports) came to slightly over 4,000 lb.[6] This corresponds to an average curb weight*** of 3,700 to 3,800 lb. The average inertia weight for 1981 is expected to be about 3,100 lb, and may further decrease to around 2,750 lb by 1985. Although the lightest cars sold here still have inertia weights close to 2,000 lb–as they did in 1975—the distribution has shifted markedly toward the lower end of the range. Many heavier models

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*Rear axle ratio is the ratio of the drive shaft speed to the axle speed.

**Transmission ratio is the ratio of the engine crankshaft speed to the drive shaft speed.

[6]J. A. Foster, j. D. Murrell, and S. L. Loos, "Light Duty Automotive Fuel Economy . . . Trends Through 1981 ," Society of Automotive Engineers Paper 810386, February 1981. Inertia weight is a representative loaded weight—equal to curb weight, which includes fuel but not passengers or luggage, plus about 300 lb–used by EPA for fuel economy testing.

***Curb weight is the weight of the car with no passengers or cargo.

have disappeared; consumers are now selecting smaller and lighter vehicles—downsized or newly designed U.S. models as well as imports.

While size is a primary determinant of weight, newer designs typically make greater use of light-weight materials such as plastics and aluminum alloys, as well as substituting higher strength steels—in thinner sections—for the traditional steels. Materials substitution for weight reduction will continue, but is constrained by the higher costs of materials with better strength-to-weight or stiffness-to-weight ratios. As production volumes go up, costs of at least some of these materials will tend to decline.

Weight is a fundamental factor in fuel economy because much of the work, hence energy, needed for a typical driving cycle is expended in accelerating the vehicle. The fuel consumed in stop-and-go driving is directly related to the loaded weight of the car (including passengers and payload) and the inertia of its rotating parts. Everything else being the same, it takes twice as much energy to accelerate a 4,000-lb car as a 2,000-lb car over the same speed range. Urban driving, in particular, consists largely of repeated accelerations and decelerations; thus, weight is critical to fuel consumption. (This also points up the potential that smoothing flows of traffic offers for gasoline savings.) Lighter cars consume less fuel even at constant speeds because they have less rolling resistance.

Although the weights of cars can be reduced by making them from lightweight materials and by shifting from separate body and frame designs to unitized construction, cars can always be made lighter by making them smaller.

Small cars can also have lower aerodynamic drag, because drag depends on frontal area as well as on the shape of the vehicle. Drag can be reduced by making cars lower and narrower, as well as by streamlining the vehicle. Drag reduction has become at least as important as styling in recent years; working primarily with wind tunnel data, automakers have reduced typical drag coefficients* from 0.5 to 0.6, characteristic of the

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*The drag coefficient is a measure of how aerodynamically "slippery" the car is. The aerodynamic drag is proportional to the drag coefficient, the frontal area and the velocity squared.
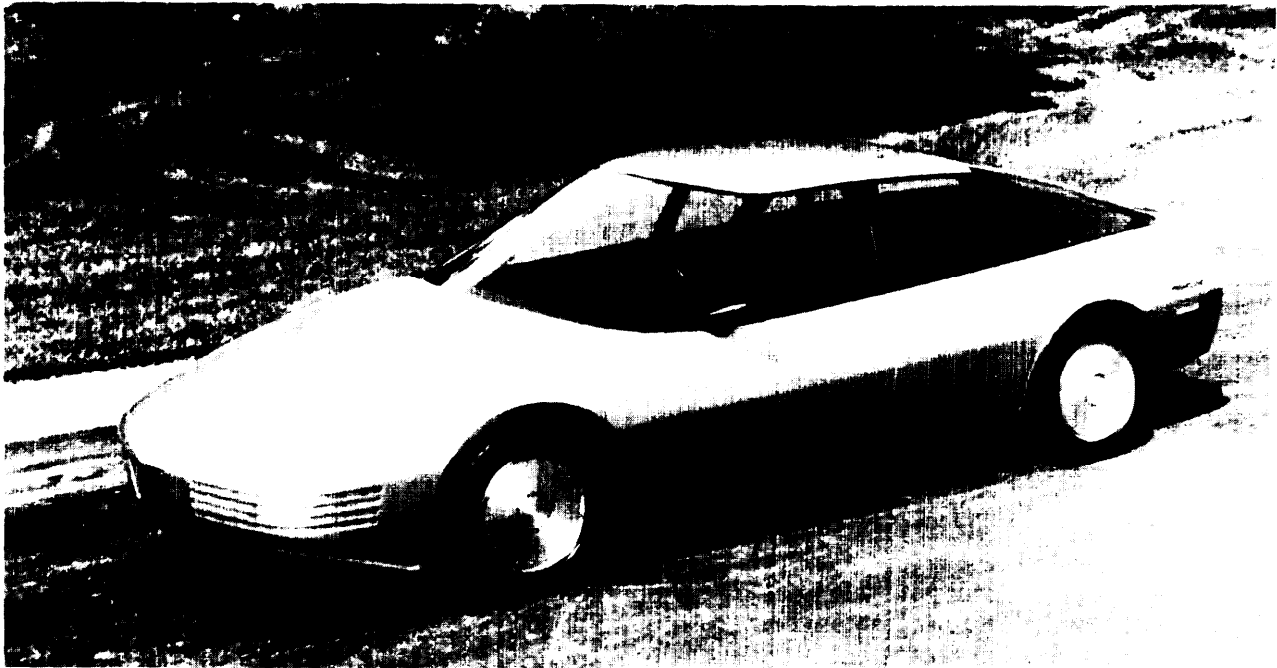
The shape of this experimental car is designed for low aerodynamic drag

early 1970's, **to 0.4 to 0.5 at present, with a number** of models being under 0.4. Values in the range of 0.35 will eventually be common.

It takes only 15 or 20 horsepower to propel a typical midsized car at a steady 55 mph—that is all that is needed to overcome rolling resistance and aerodynamic drag. The remainder of the engine's rated power is used for acceleration, climbing hills, and other demands. The low power requirements for constant-speed driving–typically 15 to 20 percent of the engine rating—emphasize the importance of the fuel used in start-and-stop driving (and the influence of weight) in determining driving-cycle fuel economy.

Powertrain

The engine (or other vehicle prime mover) converts the energy stored in fuel (or, for an EV, in batteries) to mechanical work for driving the wheels. The efficiency of the engine—as well as the efficiency of the transmission—determines the proportions of the energy in the fuel which are, respectively, used in moving the car and lost as

waste heat. Under most operating conditions, transmissions are much more efficient than the engine.

The efficiency-work output divided by energy input—of any engine depends on both detail design and fundamental thermodynamic limitations. The temperatures at which the engine operates place practical constraints on the efficiencies of some types of engines—e.g., gas turbines—but not on others—e.g., spark-ignition (SI) (gasoline) and compression-ignition (CI) (diesel) engines where the combustion process is intermittent. The components of the latter need not withstand temperatures as high as those where combustion is continuous.

Many other factors besides efficiency enter into the choice of engine for a motor vehicle; until recently, efficiency was often of secondary importance. Cars and trucks have been powered by gasoline or diesel engines because these have favorable combinations of low cost, compact size, light weight, and acceptable fuel economy. Neither demands for improvements in exhaust em is-

sions nor for better fuel economy have yet resulted in serious challenge to these engines—which have been dominant for 70 years. At least through the end of the century, most passenger cars are likely to be powered by reciprocating SI or diesel engines.

SI and CI or diesel engines have peak efficiencies generally in the range of **30** to **40** percent. However, their efficiency at *part-load* **can be** much less; the farther the engine operates from the load and speed for which its efficiency is greatest, the lower the efficiency. In typical urban driving, the *average* operating efficiency is less than one-third of the peak value–e.g., in the range of 10 to 15 percent.

Part-load fuel economy remains a more critical variable for an automobile engine than maximum efficiency because of the light loading typical of most driving. Such a requirement favors CI engines, for example, but works against gas turbines. CI engines have good part-load efficiency because they operate unthrottled, thereby avoiding pumping losses. They also have high compression ratios–which, up to a point, raises efficiency under all operating conditions.

Various modifications to SI engines can increase part-load efficiencies. This is one of the advantages of stratified-charge engines—which use a heterogeneous fuel-air mixture to allow overall lean operation, ideally without throttling as in a diesel—and also of SI engines that burn alternative fuels such as alcohol or hydrogen. Smaller, more heavily loaded SI engines also tend to have greater driving-cycle fuel economy because the higher loads mean the engine is running with less throttling. Among the steps that can be and are being taken to give greater fuel economy are:

- using the highest compression ratio consistent with available fuels;
- refined combustion chamber designs, particularly those optimized for rapid burning of lean mixtures, one of the routes to higher compression ratios;
- minimizing engine friction;
- optimizing spark timing consistent with emissions control;

- minimizing exhaust gas recirculation consistent with emissions control;
- precise control of fuel-air ratio, both overall and cylinder-to-cylinder, particularly under transient conditions such as cold starts and acceleration—again consistent with emissions control; and
- minimizing heat losses.

Transmission efficiencies also depend on load, but much less so than engines; transmission efficiencies are also much higher in absolute terms. For manual transmissions, more than 90 percent of the input power reaches the output shaft except at quite low loads. Because they have more sources of losses, automatic transmissions are less efficient, particularly those without a lockup torque converter or split-path feature. In these older transmissions, all the power passes through the torque converter, even at highway cruising speeds. The resulting fuel-economy penalty, compared with a properly utilized manual transmission, is typically in the range of 10 to 15 percent. By avoiding the losses from converter slippage at higher speeds, split-path or lockup designs cut this fuel-economy penalty approximately in half, four-speed transmissions offering greater improvement than those with only three forward gears.

One function of the transmission is to keep the engine operating where it is reasonably efficient. Although automatic transmissions are less efficient than manual designs, they can sometimes increase overall vehicle efficiency by being "smarter" than the driver in shifting gears. Further benefits are promised by improved electronic control systems for automatics. These microprocessor-based systems can sense a greater number of operating parameters, and are thus able to use more complex logic, perhaps in conjunction with an engine performance map stored in memory. Such control systems could also be used with manual transmissions—e.g., to tell the driver when to shift. A continuously variable transmission would be better still. As mentioned above, these can be built now, but they have not been practical because of problems such as high manufacturing cost, low efficiency, noise, and limited torque capacity and durability.

Fuel Economy—A Systems Problem

An automobile is a complex system; design improvements at many points can improve fuel economy. Even if each incremental improvement is small, the cumulative effect can be a big increase in mileage. Interactions among the elements of the system (engine, transmission, vehicle weight) and the intended use of the vehicle are among the keys to greater system efficiency. At the same time, as the state of the art improves, further increases in efficiency tend to become more difficult unless there are dramatic technical breakthroughs–and OTA thinks such breakthroughs are improbable. This is a mature technology in which, as a general rule, radical changes are few and far between.

Making cars smaller and lighter helps in many ways to reduce the power needed, hence fuel consumed. Front-wheel drive preserves interior space while allowing exterior size and weight to be reduced. Reductions in the weight of the body structure mean that a smaller engine will give equivalent performance, while also allowing lighter chassis and suspension members, smaller tires and brakes, and related secondary weight savings. Among other steps taken in recent years have been the adoption of thinner, hence lighter, window glass—and even redesigned window lift mechanisms.

Once major decisions have been made concerning overall vehicle design parameters—size, engine type, etc.—subsystem refinement and systems integration become the determining factors in the fuel economy achieved in everyday driving. Some of these refinements decrease the need for power, as by reducing friction or making accessories more efficient; others increase the efficiency of energy conversion, as by using three-way exhaust catalysts and feedback control of the fuel-air ratio to limit emissions while preserving fuel economy.

Tradeoffs With Safety and Emissions

Government policies to increase automobile fuel efficiency, reduce pollutant emission levels, and improve passenger safety involve significant tradeoffs. Measures to control auto emissions can impair fuel efficiency. Reducing the size of cars to increase fuel economy makes them intrinsically less safe. Meeting regulatory goals also affects manufacturing costs. Tradeoffs like these have not always been fully recognized in the formulation of Federal policy,[7] but will continue to be important as policy makers focus on questions of post-1985 fuel economy.

The issues include whether Government policies are to be directed at further improvements in mileage, such as by a continued increase in CAFE standards, or by a gasoline tax, and whether emissions standards are to be tightened or relaxed. The tradeoffs will involve manufacturing costs, as always—but the relationship of fuel economy to safety will perhaps be most critical.

Safety

The tradeoffs between fuel economy and occupant safety are largely functions of vehicle size—therefore of weight as well. Although many characteristics of the car are important for occupant safety, protection in serious collisions depends quite substantially on the crush space in the vehicle structure and on the room available within the passenger compartment for deceleration. Penetration resistance is also vital. Design requirements are based on a "first collision" between vehicle and obstacle, and a "second collision" between occupants and vehicle. In the "first collision," the more space available for the structure to crush—without encroaching on the passenger compartment-the slower the average rate of deceleration that the passenger compartment and the passengers experience. More crush space translates directly to lower decelerations.

Space, hence vehicle size, is also important within the passenger compartment. The more space available inside, the easier it is to preserve the basic integrity of the structure and the slower the occupants can be decelerated during the "second collision. " Seatbelts, for example, can stretch to lower the decelerations the restrained occupants experience, but only if there is nothing

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[7] *U.S. Industrial Competitiveness. A Comparison of Steel Electronics, and Automobiles,* **OTA-ISC-135 (Washington, D. C.: U.S. Congress, Office of Technology Assessment, June 1981), pp. 120-122.**

rigid for the occupants to hit; deformable anchors for seatbelts are thus a further method for improving safety.

Because of their larger crush space and interior volume, big cars can *always* provide more protection for their occupants in a collision—given best *practice design.* However, not all cars embody best practice designs, and the crashworthiness of autos in the current fleet does not improve uniformly and predictably with vehicle size. Furthermore, vehicle safety depends on avoiding crashes as well as surviving them, and therefore on factors such as braking and handling as well as driver ability. These and other factors related to the potential effects on auto safety of increasing fuel efficiency are discussed in chapter 10.

Emissions Control

Fairly direct tradeoffs exist between engine efficiency and several of the measures that can be used to control the constituents of exhaust gases that contribute to air pollution. The three major contributors in the exhaust of gasoline-fueled vehicles, all regulated by the Clean Air Act and its amendments, are hydrocarbons (HC), carbon monoxide (CO), and nitrogen oxides (NO_x).[8] Emissions control measures have frequently worked against the fuel economy of cars sold in the United States since 1968, when manufacturers began to retard spark timing to reduce HC emissions. Although the costs of emissions control measures—as reflected in the purchase price of the vehicle—have often been disputed and remain controversial, there have also been operating cost penalties because fuel economy has been less than it would otherwise have been.

Mileage penalties were more severe in the mid-1970's than at present, but efficiency increases have come at the expense of higher first cost. Ground is periodically lost and regained, but even with best practice technology at any given time, the engineering problems of balancing emissions and fuel economy at reasonable cost have forced many compromises. One recent estimate of the net effect of emissions control

through 1981 finds a 7.5-percent fuel-economy penalty.[9]

"The single change with the greatest continuing effect has been reduced compression ratios resulting from the changeover to unleaded gasoline. CI engines *require* high compression ratios; SI engines, in contrast, suffer from a form of combustion instability termed detonation (i.e., the engine "knocks") if the compression ratio is too high for the octane rating of the fuel. Thus, decreases in the already lower compression ratios of SI engines—to values in the range of 8:1 versus ratios as high as 10:1 in the early 1970's—have led to significant decreases in fuel economy.

Lead compounds, formerly added to gasoline to raise the octane, have been removed to prevent poisoning (deactivation) of catalytic converters—themselves adopted to control, first, HC and CO, and later NO_x **as** well–and also because of concern over the health effects of lead compounds. While electronic engine control systems, including knock detectors, have allowed compression ratios to be increased somewhat, only a portion of the ground lost can be regained in this way.

Methanol with cosolvents can be used as an octane-boosting additive to gasoline that does not interfere with the catalytic converter. In addition, compact, fast-burn combustion chambers may help. By burning the fuel fast enough that the preflame reactions leading to detonation do not have time to occur, fast-burn combustion systems might allow compression ratios to be increased by several points. This latter approach, however, increases HC and NO_x emissions, and it is not yet clear how much compression ratios can be raised while maintaining emissions within prescribed limits.

Related measures used to control emissions—and/or to limit detonation—can also degrade engine efficiency. Retarding ignition timing—to limit detonation, and in some cases help control HC and CO emissions by promoting complete combustion of the fuel–hurts fuel economy. Other techniques adopted in the early 1970's to con-

[8]D. J. Patterson and N. A. Henein, *Emissions From Combustion Engines and Their Control* (Ann Arbor, Mich.: Ann Arbor Science Publishers, 1972).

[9]L. B. Lave, "Conflicting Objectives in Regulating the Automobile," Science, May 22, 1981, p. 893.

trol HC and CO—such as thermal reactors, which were likewise intended to drive the combustion process toward complete reaction of HC and CO —also led to increased fuel consumption.

Unfortunately, while more complete combustion decreases HC and CO pollutants, NO_x in the exhaust is increased under conditions leading to more complete combustion. Thus, not only does control of exhaust emissions conflict with fuel economy, but there are also potential conflicts between control of HC and CO on the one hand, and NO_x on the other. The NO_x standards of the mid-1 970's could be met by adding exhaust gas recirculation (EGR) to the repertoire of measures used for HC and CO control. Although EGR initially carried a substantial fuel economy penalty, and also impaired driveability, improved control systems—which recirculate exhaust only when needed—have improved both economy and driveability substantially. Still, the drawbacks of other methods of NO_x control, * together with the more stringent NO_x standards of later years, have led to the most common current control technique—the three-way catalytic converter, which reduces levels of all three pollutants. This gives fuel economy comparable to an uncontrolled engine, though at higher first cost.

Compression ratios of diesel engines are often twice those for SI engines; at these high levels small changes in compression ratio have relatively little effect on efficiency. For this reason and because of the different set of emissions standards applied, CI engines have faced fewer conflicts between emissions control and fuel economy. This advantage has helped them to compete with SI engines for passenger cars, although the situation may change in the future, as the diesel standards become tougher. Particulate (bits of unburned, charred fuel) are the most difficult of diesel emissions to control, although NO_x also poses problems. However, future regulations for particulate in diesel exhaust are not yet definite. This creates uncertainty not only about the control technologies that might be needed, but also about the

future penetration of CI engines in passenger vehicles.

Nonetheless, as will be seen below, OTA remains cautiously optimistic about diesels. Their higher intrinsic efficiency at both full- and part-load makes them quite attractive in terms of fuel economy, and there is considerable scope for further improvements in their driveability and related characteristics that are more important for passenger cars than for trucks and other uses in which diesels have been more common. The long developmental history of CI engines provides a useful foundation for passenger-car applications.

Methanol-Fueled Engines

There are basically two routes to higher SI engine efficiency via alternate fuels: lean operation, which cuts pumping and other thermodynamic losses, and higher compression ratio.[10] Fuels vary in the extent to which these factors operate and there are a number of secondary effects, but alcohols and hydrogen have excellent potential for both lean burning and higher compression ratios, with possible driving-cycle economy improvements in the range of 10 to 20 percent. Further engineering development—but no breakthroughs —would be needed before alcohols or other alternate fuels could be used in U.S. cars, but the production and distribution of such fuels are more significant barriers.

Diesels, like SI engines, can operate on a variety of alternative fuels, although perhaps needing spark-assisted combustion. Powerplants such as open-chamber stratified-charge engines and continuous combustion engines can often tolerate quite broad ranges of fuels with minimal design changes.

Because methanol from coal is an attractive synthetic fuel, methanol-burning engines for passenger cars are discussed in more detail below. Unlike ethanol, which will probably be used primarily as a gasoline extender (e.g., in gasohol),

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*It should be noted, however, that burning a very lean fuel/air mixture also reduces NO_x emissions substantially. Because methanol has considerably wider flammability limits than does gasoline, the use of methanol opens new opportunities for controlling NO_x.

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[10]J. A. Alic, "**Lean-Burning Spark Ignition Engines–An** Overview," *Proceedings, 2nd Annual UMR-MEC Conference on Energy,* Rolla, **Me.,** Oct. **7-9, 1975,** p. **143.**

sufficient quantities of methanol could be produced to consider using it as the only or principal fuel for some automobiles.

If methanol-fueled engines receive intensive development aimed at maximizing fuel economy and driveability, driving-cycle fuel-efficiency improvements (on a Btu basis) of 20 percent or more should be possible, compared with a well-developed but otherwise conventional SI engine burning gasoline. Most of the improvement stems from the higher octane rating of methanol, which would permit compression ratios in the range of 11 or 12:1—perhaps even higher, depending on whether preignition is a serious limiting factor—as well as the somewhat leaner air-fuel ratios possible.

The engineering of vehicles to run on methanol —or other alchohols—is rather straightforward.[11] Indeed, a good deal of experience has already been accumulated. Despite the greater efficiency possible with methanol, vehicles fueled with

it probably will require larger fuel tanks to achieve acceptable cruising ranges, because methanol has significantly less energy per gallon than gasoline or diesel fuel. Methanol corrodes some of the materials commonly used in gasoline-fuel systems, which must be replaced by more corrosion-resistant components.

Because alcohols have much higher heats of vaporization than gasoline and therefore do not vaporize as easily, alcohol-fueled engines are more difficult to start in cold weather. Driveability during warmup also tends to be poor. Fuel injection is one approach to mitigating such difficulties. Another solution is to start and warm up the engine on a different fuel. In Brazil, where many cars and trucks run on 100 percent ethanol, engines are typically started on gasoline via an auxiliary fuel system. A lower cost alternative might be to blend in a small fraction–5 to 10 percent– of a hydrocarbon to aid in starting and warmup. Fuel blends could be tailored seasonally just as gasolines are.

Methanol also offers advantages in reducing heat losses and thus raising fuel efficiency. Al-

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[11]"CH$_3$OH: **Fuel of the Future?**" *Automotive Engineering*, **December 1977, p. 48.**

though its high specific heat and high heat of vaporization can cause starting and warmup problems, these characteristics also mean that the fuel can, in principle, be used to help control internal engine temperatures and heat flows so as to reduce heat losses.

Test programs with alcohol fuels have sometimes shown abnormally high engine wear—particularly piston ring and bore wear. While the causes have not yet been fully determined, corrosion, perhaps associated with wall-washing and crankcase dilution during cold-start, are possible contributing factors.[12] If this is the case, solving the cold-start and warmup difficulties would also be expected to cut down on wear. Oil additive packages specially tailored for alcohols should be a further help.

Emissions from methanol-burning automobiles can be controlled with many of the same technologies used for gasoline engines. However, because of the differing fuel chemistries, standards developed for gasoline-burning vehicles are not necessarily appropriate for alcohols. Aldehydes, for example, may need to be controlled.

Battery-Electric and Hybrid Vehicles

The automobile powerplants considered by OTA for increased fuel efficiency are all heat engines–i.e., they convert the energy (heat) produced when a fuel burns into mechanical work. Passenger cars can also be powered from energy stored in forms other than fuel—e.g., by mechanical energy drawn from a spinning flywheel. Among these alternative storage media are rechargeable batteries that convert chemical energy into electrical energy. The electric energy can then drive a direct current (DC) (or sometimes, through an inverter, an alternating current (AC)) motor. Many of the first automobiles built, around the turn of the century, used battery-electric power.

In an extension of the battery-electric concept —called a hybrid—a conventional heat engine drives a generator (or alternator) which can then supply power to an electric motor directly, charge batteries, or both–depending on the instantaneous needs of the driving cycle. A parallel hybrid is designed so the heat engine can also power the wheels directly, through a transmission (the engine turns the generator and the drive wheels in parallel). A series hybrid, in contrast, has no direct mechanical connection between heat engine and drive wheels. Diesel-electric submarines provide examples of both series and parallel hybrid powertrains, but automobiles have never been mass produced with either arrangement.

Whether or not a battery-electric or hybrid automobile would have an overall energy conversion efficiency greater or less than a more conventional SI- or CI-powered car depends on many variables, including the sources of the electricity used to charge the batteries. In the context of this report, the potential of battery-electric or hybrid vehicles as substitutes for petroleum-based fuels is more important than the net energy conversion efficiency. If the electricity for charging the batteries comes from a coal or nuclear generating plant—or any other nonpetroleum energy source—widespread sales of such cars could help conserve liquid petroleum.

At present, however, the limitations of practical electric and hybrid vehicles far outweigh any advantages that might be gained from their petroleum-displacing effects.[13] Battery-electric cars will have very limited applications until the performance of batteries (as measured, for example, by the quantity of energy that can be stored per unit of battery weight), increases roughly fivefold— or unless petroleum availability declines much more rapidly than now expected. Hybrids share many of the disadvantages of battery-electric cars and—although they offer theoretically promising energy conversion efficiencies—are dependent on fuels. Their current prospects are even dimmer than for battery-electrics, in large part because hybrid vehicles would be expensive and complex—the duplication in the powertrain is a formidable cost barrier.

[12]T. W. Ryan, III, D. W. Naegeli, **E. C.** Owens, H. W. Marbach, **and J, G. Barbee, "The Mechanism Lending to Increased Cylinder Bore and Ring Wear in Methanol-Fueled S.1. Engines, " Society of Automotive Engineers** Paper **811200, 1981.**

[13]R. L. Graves, C. D. **West, and E. C. Fox, "The Electric** Car—Is It Still **the Vehicle of the Future, " Oak Ridge National Laboratory Report** ORNL/TM-7904, **August 1981.**

Despite the widespread publicity given to battery-electric automobiles over the past 20 years—most recently, the attention garnered by General Motors' announcement of production plans for the mid-1980's—progress in EVs remains severely limited by battery performance. This is true both for battery systems that are available now and for those that appear to have possibilities for near-term production. Power and energy densities of available batteries remain too low for practical use in other than highly specialized automotive applications. Power density (watt per pound or W/lb) measures the *rate* at which the battery can supply energy. Energy density (watt hours per pound or Whr/lb) measures the total *amount* of energy that can be stored and then withdrawn from the battery. For some battery systems, to get all the energy out requires a slow rate of withdrawal, limiting the instantaneous delivery of power. Because of the transient demands of automotive driving cycles, power density is almost as important for vehicle applications as energy density, which determines the operating range before the batteries need to be recharged.

In general, battery systems that are near-term candidates for automotive applications suffer from both low power density *and low* energy density. Table 20, which includes several batteries that are still in rather early stages of development, gives typical values. Energy and power density tend to be inversely related, a particular problem for the familiar lead-acid battery; the inverse relation means that—for any given battery system—the designer can choose higher energy density only at the sacrifice of power density. Limited power density restricts the acceleration capabilities of current **EVs** to low levels—for some driving conditions, to the detriment of safety. The en-
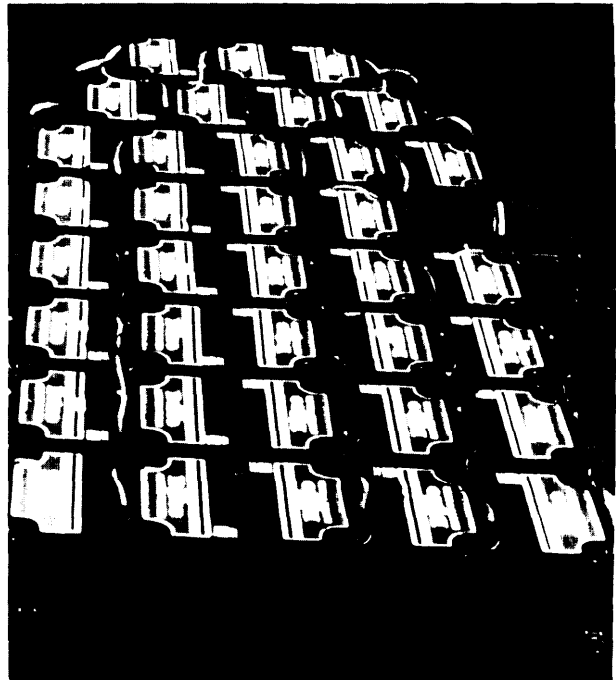

Photo credit: Electric Vehicle Council

A view of the battery-pack configuration in a demonstration electric vehicle

ergy density, in contrast, limits the total amount of energy that can be carried, therefore, the range of the vehicle before the batteries must be recharged. Recharging is a time-consuming process—as much as 10 hours for some, though not all, batteries. If power density and energy density are low, then the vehicle must carry more batteries. This makes it heavier, increasing the demands for power and energy and compounding the design problems.

As a rule-of-thumb, and assuming reasonable costs, an energy density in the vicinity of 100

Table 20.-Potential Battery Systems for Electric (and Hybrid) Vehicles

Battery	Energy density (Whr/lb)	Power density (W/lb)	Status
Lead-acid	15-20	5-20	Available
Nickel-zinc	30-40	40-80	Available, but expensive
Zinc-chlorine	~35	~50	Experimental; potentially inexpensive
Aluminum-air	100-200	~80	Experimental; cannot be electrically recharged (requires periodic additions of water and aluminum)
Sodium-sulfur.	~100	~100	Prospective; high-temperature; potentially inexpensive

SOURCE: Office of Technology Assessment.

Whr/lb, along with a power density of about 100 W/lb, would suffice for a practical general-purpose vehicle. With these characteristics, 400 lb of batteries would give about 100 miles of travel between battery recharging and produce about 55 horsepower. Urban or commuter cars might get by with somewhat lower figures. Table 20 shows that currently available battery systems either cannot achieve such figures, or—as with nickel-zinc batteries-are too expensive for widespread use.

Battery-electric cars–often production vehicles converted by replacing the engine and fuel system with an electric motor and lead-acid batteries (like the storage batteries used in golf carts) -have been built in prototype or limited-production form for years. At present, a four-passenger electric car with lead-acid batteries would weigh about twice as much as a conventionally powered car, cost twice as much, and have a range of less than 50 miles before recharging. The bat-*tery pack alone would weigh 1,000 lb or more,* and would have to be replaced several times during the life of the vehicle, adding to the operating costs.

In addition to the nickel-zinc batteries mentioned above, there are a number of other candidate battery systems for EVs–of which table 20 includes three as examples—the zinc-chlorine, aluminum-air, and sodium-sulfur batteries. These share the advantage of relatively inexpensive raw materials, but have other drawbacks: for example, the zinc- chlorine battery has low energy density; the aluminum-air system is "recharged," not by an inward flow of electricity, but by mechanical replacement of materials (in consuming materials to produce electricity the aluminum-air battery is like a fuel cell, but fuel cells are continuous-flow devices); the sodium-sulfur battery operates at temperatures greater than 5000 F. All of these batteries are experimental, and none has been developed as rapidly as once hoped; the same is true of many other candidate

battery systems with theoretically attractive characteristics for EVs and/or hybrid vehicles.[14]

Not only are battery-electric cars severely limited in range and performance by the energy and power densities of available batteries, but production costs would also be high, at least initially. A further and serious disadvantage is the limited life of many prospective battery *systems.* Often, the batteries would need to be replaced–at high cost—before the rest of the vehicle reached the end of its useful life. Battery-electric cars also pose new and different safety problems, such as spills of corrosive chemicals in the event of an accident,

Battery-electric powertrains may have a place in local delivery trucks, and perhaps for small, specialized commuter cars. More widespread use depends on large improvements (a factor of at least 5 in battery performance, particularly energy density). Although research and development (R&D) on battery systems for EV applications will continue, there seems little likelihood of significant production—i. e., hundreds of thousands of vehicles per year—before the end of the century. "Breakthroughs" in batteries are improbable; slow incremental progress is more likely to characterize R&D on battery systems, and hence EV (and hybrid) vehicles. Moreover, by the time battery performance is improved sufficiently for practical application, progress in fuel-cell technology may make the latter a more attractive option. (Fuel cells convert a fuel, now generally hydrogen but potentially a hydrocarbon or methanol, directly to electricity.)

Hybrids also are limited by battery performance, but the on board charging capacity means that not as many batteries are needed, so the bat-

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[14]A. R. Landgrebe, et al., **"Status of New Electrochemical Storage and Conversion Technologies for Vehicle Applications, "** *Proceedings of the 16th Intersociety Energy Conversion Engineering Conference,* **Atlanta,** Ga., **Aug. 9-14, 1981, Vol.** 1 **(New York: American Society of Mechanical Engineers, 1981), p. 738.**

tery **pack is lighter.** However, hybrids must carry a complete heat engine, as well as a generator or alternator, and an electric drive motor. Although the engine can be small, because it need not be capable of powering the vehicle by itself, the cost and complication of the hybrid powertrain are prohibitive, at least at present. The complication comes not only from the duplicate energy conversion and drive systems but also from the control system. While the performance requirements for the control system are not unusual, the need for a reliable, mass-produced system at reasonable cost does create a demanding set of constraints. The added weight of the batteries and duplicate drivetrain, and the efficiency losses associated with recharging the batteries, also tend to counteract the theoretical advantages of hybrids in fuel economy.

FUTURE AUTOMOBILE FUEL EFFICIENCY

Automobile technology is not a major constraint on fuel economy. Small cars can be designed today—indeed, are on the market—with mileage ratings twice the current new-car average. Technology *is* important for increasing the fuel economy of the larger, more powerful, and more luxurious cars that many Americans still desire. Evolutionary improvements will continue to increase the mileage of both large and small cars, but the pacing factor at the moment is market demand.

Because consumer demand is unpredictable, estimates of post-1985 fuel economy are uncertain; these estimates largely reflect expectations of the importance consumers will place on size and gas mileage. Projections of the fuel economy that the U.S. new-car fleet will achieve vary widely, but most now tend to be optimistic. Only 2 or 3 years ago, American automakers viewed the CAFE standards, correctly, as pushing their product lines away from the sorts of cars that most consumers still demanded. Now many of those same consumers are buying cars with average fuel economies above the CAFE requirements.

EPA statistics indicate that average domestic new-car fuel economy averaged almost 24 mpg for 1981 models sold through January 5, 1981.15 If imports are included, the figure is about 25 mpg. A few predictions are as high as 90 mpg for 1995 or 2000, although such projections are usually exhortations rather than realistic attempts to project future trends. While the technology to achieve such efficiencies will exist, fleet averages are likely to remain well below the economy ratings that the best performers will be able to achieve.

The primary differences among the many projections of automobile fuel economy for the years ahead arise from varying assumptions of future market demand. Different assumptions for the rate of introduction of new technology are also common. A constraint for American manufacturers may be the ability to generate and attract capital for R&D and for investment in new plant and equipment, particularly if movement toward small, high-mileage cars and introductions of new technology are more rapid than domestic firms have been anticipating. Many foreign automakers already produce cars that are smaller and lighter —and get better fuel economy—than those they now sell in the United States.

Although the fuel economy achieved by the new-car fleet in future years will depend strongly on market demand and the health of the auto industry, technology is also important. Both the timing of new vehicle designs and their ultimate costs—whether routine downsizing and materials substitution, or more demanding tasks such as improved powerplants—depend on extensive programs of engineering development. These take time and talent, as well as money. Complete success can never be guaranteed. Some projects will have more satisfactory outcomes than others.

To distinguish these technological dimensions from questions of market demand, the discussion below first outlines two scenarios for future developments in automobile technology. Designated the "high-estimate scenario" and the "low-esti-

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1⁵'' Light Duty Automotive Fuel Economy . . . Trends Through 1981 ,'' op. cit.

mate scenario, " they represent plausible upper and lower bounds for fleet average passenger-car fuel economy in future years. Of course, among the cars on the market in any year, some would have mileage ratings considerably below, some considerably above, the fleet averages for that year. These scenarios are independent of market demand for cars of various size classes, and are simply based, respectively, on optimistic and pessimistic expectations for rates of advance in automobile technology as these affect fuel economy. Using these scenarios, later sections of the chapter discuss the effect of market demand on the fuel economy of the U.S. auto fleet.

Technology Scenarios

Both the high- and low-estimate technology scenarios take as a baseline the new-car fuel economy now expected for 1985. This baseline includes a "number of technical advances, as well as further downsizing, compared with 1982 model cars. While the product plans of individual manufacturers for 1985 are not known in detail, the broad outlines of 1985 passenger-car technologies can be easily discerned. The scenarios then cover the period 1985-2000. The high *estimate* assumes:

- that engineering development projects aimed at improving fuel economy are generally successful;
- that these technological improvements are quickly introduced into volume production; and
- that they produce fuel economy improvements at the high end of the range that can now be anticipated.

The low *estimate* assumes, in contrast:

- that development projects are not as successful–e.g., that technical problems decrease the magnitude of fuel-economy gains, lengthen development schedules, and/or result in high production costs;
- the pace of development is slower than would result from the vigorous efforts to "push" automotive technology assumed for the high estimate scenario; and

- the resulting fuel-economy improvements are at the low end of the range that can now be anticipated.

From a technological perspective, the vehicle subsystem most critical for fuel-economy improvements is the powertrain-i.e., the engine and transmission. Here, as in other aspects of automotive technology, more-or-less continuous evolutionary development can be expected. But major changes in powertrains have also been occurring—e.g., new applications of diesel engines to passenger cars.

The pace of development may vary for other aspects of automobile technology—aerodynamics, downsizing and weight reduction, power consumption by accessories—but individual innovations with large impacts on fuel economy are unlikely. Engine developments, in contrast, depend more heavily on successful long-term R&D programs; fundamental knowledge–e.g., of combustion processes–is often lacking, and the risks as well as the rewards can be large. In contrast, development programs aimed, for instance, at friction reduction, are likely to be more straightforward–and less costly.

Table 21 presents OTA's high and low estimates for improvements in fuel economy by category of technology, based largely on informed technical judgments. * Relative to an assumed 1985 car which gets 30 mpg (EPA rating, 55 percent city, 45 percent highway driving cycle), table 21 indicates that gains of 35 percent in fuel economy may be possible from engine redesigns, but that percentage improvements in transmissions and vehicle systems are likely to be smaller. Nonetheless, the cumulative improvements in fuel economy can be quite large.

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*Alternative methodologies for estimating future fuel economy— e.g., the use of learning curves, or analytical modeling of the vehicle system—generally lead to comparable results. All approaches to projecting fuel economy have their limitations. The method adopted by OTA does not always do the best job of evaluating the systems effects of combining different technologies—i.e., open-chamber diesel engines combined with four-speed lockup torque converters. Learning curves, based on historical trends, do not take explicit account of new technologies. Analytical modeling is a valuable tool for comparing alternative technologies, but models *must* be validated by comparison with hardware results before the model can be used with confidence.

Table 21.–Prospective Automobile Fuel-Efficiency Increases, 1986-2000

| | Percentage gain in fuel efficiency | | | | | |
| | High estimate | | | Low estimate | | |
Technology	1986-90	1991-95	1996-2000	1986-90	1991-95	1996-2000
Engines						
Spark-ignition (SI)	10	10-15	15	5	5-1o	5-1o
Diesel:						
Prechamber. , ... ,.	15	15		15	15	
Open chamber	25	35	35	20	20	25
Open chamber (SI) stratified charge (SC)		15	20			
Hybrid diesel/SC			35			
Transmissions						
Automatic with lockup torque converter	5	5	5	5	5	5
Continuously variable ((XT).		10	15			10
Engine on-off		10	10			10
Vehicle system						
Weight reduction (downsizing and						
materials substitution)	8	13	18	4	8	10
Resistance and friction (excluding engine)						
Aerodynamics. . . . . ,. . . .	2	3	4	1	2	3
Rolling resistance and lubricants	1	2	3	1	1	2
Accessories	2	3	4	1	1	2

a improvements in fuel efficiency are expressed as percentage gain in mpg compared with an anticipated average 1985 passenger car. The 1985 average car used as a reference has an Inertia weight of about 2,500 lb, is equipped with spark-ignition engine, three-aped automatic transmission, and radial tires, and has an EPA mileage rating (55 percent city, 45 percent highway) of 30 mpg. The fuel efficiencies of the individual baseline cars, which are used to calculate future fuel efficiencies in each size class, are given In tables 23 and 24. Percentages are given on an equivalent Btu basis where appropriate—e.g., for diesels, which use fuel having higher energy content per gallon than gasoline, the percentage gain refers to miles per gallon of gasoline equivalent, which Is 10 percent less than miles per gallon of diesel fuel. The table does not include efficiency improvements from alternate fuels such as alcohol.

SOURCE: Office of Technology Assessment.

None of the figures in this table should be interpreted as predictions. Rather, they illustrate ranges in fuel-economy improvement, based on OTA's judgment of what is likely to be technically practical. The projected improvements are not directly associated with the developmental programs of specific automobile manufacturers—either domestic or foreign. As changes in automobile technology occur, older designs will coexist with new—just as, recently, older V-8 SI engines have remained in production alongside replacements such as diesels and V-6 SI engines. New engines and transmissions are typically introduced with the presumption that they will remain in production for at least 10 years. These rather slow and gradual patterns of technological change are likely to continue unless market conditions force an acceleration. For this to happen, the market pressures would have to be rather intense, if only because of the limited capital resources available at present to the domestic automakers.

Table 21 lists the net improvements in automobile components that could be expected, on the average, for the high and low estimates during each 5-year period. Note that the technologies listed in the table are not in every case compatible with one another, nor can any simple combining procedure yield net figures that have clear and direct meaning for particular hypothetical vehicles. This is because different technologies combine in different ways. For example, the poor part-load efficiencies of throttled SI engines mean that continuously variable transmissions and engine on-off will yield greater improvements than for partially throttled open-chamber stratified-charge engines or diesels. Thus, the choice of cost-effective technologies cannot be inferred from such a table alone, but must depend on more detailed analysis, and finally on testing.

The technologies listed in table 21 are discussed in more detail in appendix 5A at the end of this chapter.

Projection of Automobile Fleet Fuel Efficiency

Based on the technological scenarios in table 21 and several assumptions about the size mix of new cars, OTA has constructed a set of pro-

jections for the fuel economy of passenger cars sold in the U.S. market in future years. As emphasized earlier in this chapter, market demand—not technology—is the key factor in determining the mileage potential of the new-car fleet, Market demand is particularly critical in determining the size mix of new-car sales.

The automobile technologies listed in table 21 are more important as tools for increasing the fuel economy of the larger, more luxurious cars that many American purchasers still demand than for cars that are small and light—e.g., nearly all current imports, as well as the new generations of American-made subcompacts. Improved powertrains and the use of materials with high strength-to-weight ratios will lead to improved fuel economy in cars of all sizes. But a 10-percent increase in gas mileage for a big car—with mileage that is initially low—saves more fuel than a 10-percent improvement to a small car that is already more fuel efficient.

This is not to say, however, that a given technological development will necessarily give the same percentage improvement for cars of all sizes—or even be applicable to all types of cars. Continuously variable transmissions (CVTs) have been in limited use for many years in small cars, and would no doubt be applied widely in subcompacts before finding their way into heavier vehicles. The reason is simply that the mechanical design problems for a CVT are simpler if the levels of torque that must be transmitted are low.

On the other hand, if gas turbines become practical as automobile powerplants, they are likely to be used first–and perhaps exclusively–in big cars, because turbine engines are more efficient in larger sizes.

Any projection of fleet fuel economy will depend on the assumed weight (size) mix of new-car sales in the years ahead. For its analysis, OTA adopted a simplified description of this mix, based on three size classes–small, medium, and large. This allows possible market shifts to be analyzed in terms of the assumed proportion of new-car sales by size class—for each of which the average fuel economy has been estimated. This is a considerable abstraction from the real situation –-one in which the spectrum of curb weights from which consumers select extends from less than 2,000 lb to over 4,000 lb. For any given weight—now and in the future—there will also be a range of fuel economies, depending on vehicle design. The convenience of the description in terms of only three size classes, for which other characteristics are averaged, comes at the expense of the richness and variety that will actually exist in the marketplace.

New-Car Fuel Efficiency by Size Class

Table 22 describes the small, medium, and large size classes on which OTA's projections are based. The scheme is similar to current EPA practice for fuel-economy ratings—grouping cars of similar passenger capacity and interior volume. However, the designations of car sizes in table 22 differ from some current designations because they are intended to reflect future vehicle characteristics rather than the past; in other words, OTA prefers to call a future small car just that, not a ''m in i compact ." Each class in the table encompasses a considerable range of possible vehicle designs. Under either the high or low estimate scenarios, curb weights of cars in the U.S. fleet are expected to decrease over the period 1985-**2000.**

Table 22.–Small, Medium, and Large Size Classes Assumed for 1985-2000

| Class | Curb weight[a] (lb) | | Interior volume (ft³) | Passenger capacity | 1981 equivalents | |
	High estimate	Low estimate			Size class	Typical models
Small	1,300-1,600	1,400-1,700	< 85	2-4	Minicompact, two seaters	Honda Civic Toyota Starlet
Medium.	1,600-2,000	1,700-2,000	80-110	4	Subcompact, compact	VW Rabbit Chrysler K-Car
Large.	2,200-3,000	2,500-3,000	100-160	5-6	Intermediate, large, luxury	GM X-Car Ford Fairmont

[a]**Curb weight is the weight** of the car without passengers or cargo.

SOURCE: Office of Technology Assessment.

Tables 23 and 24 expand on the descriptions in table *22.* For these tables, OTA has **estimated weight averages, engine alternatives, and average fuel economies at 5-year intervals through 2000** for the two technology scenarios. **Again, these estimates reflect informed technical judgment but should not be viewed as predictions.** The curb weights are averages expected for each of the three size classes; rather broad ranges in actual weights are likely, especially in the medium and large classes. The fuel **economy estimates are** likewise averages with considerable spread anticipated. Fuel economy projections are given in terms of current **EPA rating practice (combined city-highway figures)—which overestimate actual over-the-road mileage by as much as 20 percent.** The EPA rating basis has been adopted for ease of comparison with fuel economy ratings for the current fleet; in later sections, to estimate actual fuel consumed, EPA ratings are adjusted downward to more realistic values.

The average fuel economy estimates in tables 23 and 24 for the high- and low-estimate technology scenarios are grouped together in table 25 so that the differences by size class and technol-

ogy level can be more easily compared. Table 25 illustrates the importance of size and weight for fuel economy. By 2000, the low-estimate average efficiency for medium-size cars is the same as the high-estimate efficiency for big cars—both are 50 mpg. Large cars show the greatest percentage improvements because more can be done to improve fuel economy before diminishing returns become severe.

One way to abstract the effects of downsizing and weight reduction from other technological improvements is to examine specific fuel economy—by normalizing to ton-mpg, or the miles per gallon that would result for an otherwise similar car weighing 1 ton. Ton-mpg values have exhibited an upward trend overtime as automotive technologies have improved.[16]

Figure 9 shows the gradual increase–with considerable year-to-year fluctuations—that has characterized average fuel economy in ton-mpg for the U.S. new-car fleet over the past decade, together with estimates through 2000 based on the

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[16]**"Powerplant Efficiency Projected Via Learning Curves, "** *Automotive Engineering* **July 1979, p. 52.**

Table 23.—Automobile Characteristics- High-Estimate Scenario

	Small				Medium				Large			
	1965	1990	1995	2000	1965	1990	1995	2000	1985	1990	1995	2000
Average curb weight (lb)	1,600	1,500	1,400	1,300	2,000	1,800	1,700	1,600	3,000	2,600	2,400	2,200
Engine type (percent):												
Spark ignition		100	95	70	60	90	70	50	30	75	30	30	25
Prechamber diesel	—	5	—	—	10	10	—	—	25	40	—	—
Open chamber diesel or open												
chamber stratified charge	—		30	40		20	50	70	–	30	70	75
Fuel economy[a] (mpg)	48	62	74	84	39	51	61	71	27	37	43	49

[a]Combined EPA clty/highway fuel-economy rating, baaed on 55 percent city and 45 percent highway driving.

SOURCE: Office of Technology Assessment.

Table 24.—Automobile Characteristics-Low-Estimate Scenario

	Small				Medium				Large			
	1965	1990	1995	2000	1985	1990	1995	2000	1985	1990	1995	2000
Average curb weight (lb)	1,700	1,600	1,500	1,400	2,000	1,900	1,600	1,700	3,000	2,600	2,600	2,500
Engine type (percent):												
Spark ignition	100	100	100	60	90	60	70	70	75	60	50	40
Prechamber diesel	—	—	—	—	10	20	30			25	40	20	
Open chamber diesel	—	—	—	40	—	—	—	3	0	-	-	-	3	O	G
Fuel economy[a] (mpg)	45	52	57	65	35	41	45	50	23	28	31	34

[a]Combined EPA city/highway fuel-economy rating, baaed on 55 percent city and 45 percent highway driving.

SOURCE: Office of Technology Assessment.

**Table 25.—Estimated New-Car
Fuel Economy: 1985-2000**

Size class	Average new-car fuel economy[a]			
	1985	**1990**	**1995**	**2000**
Large:				
High estimate	27	37	43	49
Low estimate	23	28	31	34
Medium:				
High estimate	39	51	61	71
Low estimate	35	41	45	50
Small:				
High estimate	48	62	74	84
Low estimate	45	52	57	65

[a]**Combined** EPA city/highway fuel-economy rating, based on 55 percent city and 45 percent highway driving.
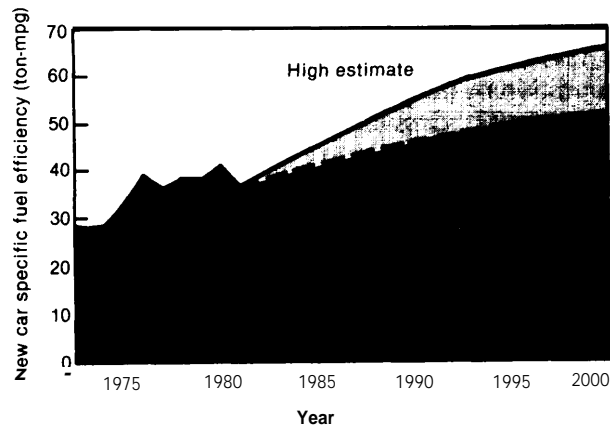
SOURCE: Office of Technology Assessment.

**Figure 9.—Sales.Weighted Average New-Car Fleet
Specific Fuel Efficiency**

SOURCE: Off Ice of Technology Assessment.

high and low scenarios in table 21. As for the earlier tables, figure 9 aggregates both domestic automobiles and imports. Using such projections, the fuel economies of future new-car fleets of various size (weight) mixes can be estimated.

As the figure shows, average specific fuel consumption for new cars sold in the United States has increased from less than 30 ton-mpg in the early 1970's to roughly 39 ton-mpg in 1981, a 30-percent improvement. The most efficient 1981 cars sold in this country gets 50 ton-mpg. * By 1990, the average should equal the current best. By 2000, the *average* could be as high as 65 ton-mpg.

Based on the projections in tables 23-25, or alternatively those in figure 9, the effects of changes in the size mix of the new-car fleet can be estimated. In the mix of new 1981 cars sold through January 5, 1981, small cars made up only 5 percent of the market; the rest was almost evenly divided between medium cars (48 percent) and large cars (47 percent). By 1985, the share of small cars may remain at 5 percent, but the share of medium cars is expected to go up at least to 60 percent, dropping the large-car share to 35 percent or less. Even in the unlikely event that the 60:35, ratio remains unchanged beyond 1985– that medium cars show no further sales gains over large cars–the average fuel economy of the new-car fleet in 2000 would be 62 mpg in the high-estimate scenario, 43 mpg in the low-estimate scenario. * (See table 26, "no mix shift" case.) These figures represent a substantial improvement over the 25 mpg expected in 1981 and the 30 to 35 mpg expected for 1985. A further shift in consumer preference toward smaller and lighter cars would increase the expected fleet-average fuel economy even more.

To illustrate the effects of a continuing shift towards smaller and lighter cars, table 26 also gives average fuel economies at 5-year intervals for a "moderate" mix shift-leading to 35 percent small cars, 50 percent medium cars, and 15 percent large cars by 2000-and for a "large-scale" mix shift. The latter assumes 70 percent small cars, 25 percent medium cars, and only 5 percent large cars in 2000. **As** the table shows, the large-scale mix shift could give a new-car fleet average fuel economy of 60 to 80 mpg by 2000. Whether market demand will lead to such a mix shift depends on factors such as price differentials between large and small cars, and the compromises in other vehicle characteristics that accompany smaller cars, as well as the pricing and availability of fuel.

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*These are diesels, for which the ton-mpg rating has been expressed on a gasoline-equivalent basis; the value based on diesel fuel would be about 55 ton-mpg. The best current SI engine models sold in the United States have ton-mpg ratings about 10 percent lower, or roughly 45 ton-mpg.

*The corresponding numbers for the 1981 mix are 59 mpg in the high estimate and 41 mpg in the low estimate.

Table 26.—Effect on Size Mix on Estimated Fuel Economy of the New-Car Sales in the United States

| Technology scenario | Estimated average new-car fuel economy[a] (mpg) | | | | | | | | | | | |
| | No mix shift[b] | | | | Moderate mix shift[c] | | | | Large-scale mix shift[d] | | | |
	1985	1990	1995	2000	1985	1990	1995	2000	1985	1990	1995	2000
High estimate	34	45	54	62	34	48	59	70	37	53	65	78
Low estimate	30	36	39	43	30	38	43	51	33	43	49	58

[a] 55 percent city, 45 percent highway EPA rating.
[b] The no mix shift case assumes:

Size class	Sales mix (percent) for all years
Small . .	5
Medium	60
Large . .	35

[c] The moderate mix shift assumption is as follows:

| Size class | Sales mix (percent) | | | |
	1985	1990	1995	2000
Small . . .	5	15	25	35
Medium	60	60	55	50
Large	35	25	20	15

[c] The large-scale mix shift assumption is:

| Size class | Sales mix (percent) | | | |
	1985	1990	1995	2000
Small	10	30	50	70
Medium . .	75	65	45	25
Large	15	5	5	5

SOURCE: Office of Technology Assessment.

ESTIMATED FUEL CONSUMPTION, 1985–2000

In this section estimates of the fuel consumed by the U.S. passenger-car fleet are based on the various assumptions and projections of car size mix and efficiency discussed above, but assume that gasoline and diesel fuel continue to power passenger vehicles, with no significant penetration of alternative fuels such as methanol.

In 1975, when Federal fuel economy standards were enacted, passenger cars consumed an average of about 4.3 MMB/D of fuel. (Trucks are omitted from the calculations in this chapter, but many light trucks and vans are used interchangeably with passenger cars and add about 1.1 MMB/D to average consumption). Passenger-car fuel consumption rose to 4.8 MMB/D in 1978, but has since declined to 4.3 MMB/D–about the 1975 level.[17] OTA projects that passenger-car fuel consumption will continue to decline—to about 3.6 MMB/D in 1985, as the automobile fleet becomes more fuel-efficient. This estimate assumes that the fleet will grow from about 107 million cars in 1980 to 110 million in 1985, and that the average car will continue to accumulate about 10,000 miles per year.

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[17]Derived from J. K. Pollard, et al., "Transportation Energy Outlook: 1985-2000," Transportation Systems Center, U.S. Department of Transportation, DOT-TSC-RS-1 12-55-81-6, September 1981, pp. 4-21; and "Monthly Energy Review, " Energy Information Agency, U.S. Department of Energy, DOE/EIA-0035 (81/10), October 1981.

Projected Passenger-Car Fuel Consumption

The baseline chosen for discussing fuel consumption by passenger cars past 1985 is outlined in table 27. Growth in the automobile fleet—which depends on both sales levels for new cars, and the rates at which older cars are scrapped—is

Table 27.—Baseline Assumptions for Projections of Automobile Fuel Consumption

	1980	1985	1990	1995	2000	2005	2010
Vehicle miles of travel:							
Trillion miles/yr . . .	1.14	1.17	1.20	1.23	1.26	1.28	1.31

Also assumes 47 percent of fleet vehicle miles traveled (VMT) by cars less than 5 years old, 38 percent of VMT by cars 5 to 10 years old, and 15 percent of VMT by cars older than 10 years.

New-car fuel economy (combined EPA ratings; 55 percent city, 45 percent highway)
1985 base case (low-high estimate)
  Small cars: . . . . 45-48 mpg
  Medium cars: . . . . 35-39 mpg
  Large cars: . . . . 23-27 mpg
Fleet baseline average efficiency 30 mpg, 1985-2010
High- and low-estimate scenarios
  See table 25

On-the-road fuel efficiency:
10 percent less than EPA rated fuel efficiency

Size *mix:*
See table 26
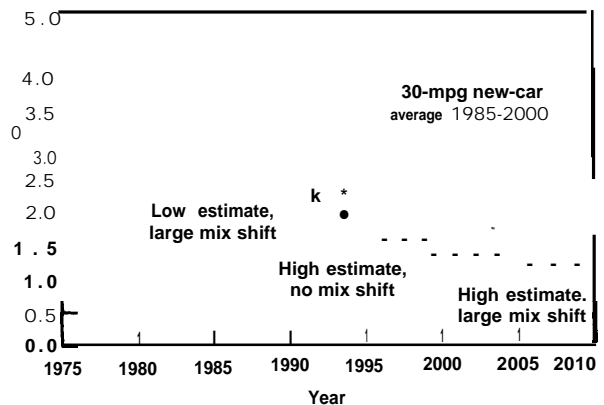
SOURCE: Office of Technology Assessment.

projected to average less than 2 percent per year.[18] Cars are assumed to be driven an average of 10,000 miles per year, with newer cars driven more and older cars driven less, on the average (see table **27).** The projections for new-car fuel economy and future size mix are taken from the tables in earlier sections. Because those fuel-economy projections were based on EPA ratings, which overestimate actual on-the-road mileage, fuel economy has been adjusted downward 10 percent to compensate.

If neither fuel economy nor size mix were to advance past a 1985 baseline average of 30 mpg, fuel consumption by passenger cars would still decline slowly for 10 years, reflecting the larger fraction of cars in the fleet with fuel economies at this baseline value, Between 1985 and 1995, passenger-car fuel consumption would decline– even with a status quo in fuel economy and size mix—from about 3.6 MMB/D in 1985 to 2.7 MMB/D in 1995. Thereafter, the upward trend would resume because of increases in the total size of the fleet.

But of course, automobile technology will continue to improve (table 21), and a continuing shift toward smaller cars is also probable (table 26). Therefore, under almost any realistic set of assumptions, passenger-car fuel consumption will continue to decrease during the post-1995 period. At some point it may still turn upward because of increases in fleet size, this turning point depending on both technology and size mix. In any case, as figure 10 shows, the decline in passenger-car fuel consumption will level off by about 2005 (unless growth in the fleet is slower than projected in table 27 or cars are driven fewer miles per year).

Figure 10 gives fuel-consumption projections to 2010 based on these assumptions. The influence of technological improvements is striking. For example, even without a mix shift toward cars smaller than in the 1985 baseline mix, the high estimate gives fuel savings greater than those for the low estimate with a large-scale shift towards smaller cars. But such a mix shift would also create substantial fuel savings. For the cases plotted

[18] *U.S.Industrial Competitiveness: A Comparison of Steel, Electronics, and Automobiles,* **op. cit., pp. 140-141.**

Figure 10.—Projected Passenger-Car Fuel Consumption

SOURCE: Off Ice of Technology Assessment.

in this figure, passenger-car fuel consumption stays well below 2.5 MMB/D during the early years of the next century. The figure also shows the potential benefits if technical success is accompanied by a strong shift to smaller cars. The difference in 2010 between the low estimate with no mix shift (about 2.0 MM B/D), and the high estimate with a large mix shift toward smaller cars (1.1 MMB/D), is nearly a factor of 2. The lower end of this range is about one-fourth the current level of fuel consumption. Where within this range the actual fuel consumption would fall is likely to depend–as emphasized earlier–on market demand for fuel-efficient vehicles, and/or continuing Government policies designed to encourage the manufacture and purchase* of fuel-efficient cars. Changes in vehicle miles traveled would also change the fuel consumption proportionately.

*An illustration of the importance of new-car sales can be derived as follows: In 1980, 47 percent of the vehicle-miles traveled (VMT) were by cars 0 to 4 years old, 38 percent by 5 to 9 year old cars, and 15 percent by cars 10 years old and older. Call this the base case. A persistent 20 percent depression in new car sales could change the VMT distribution by 1995 to: 40 percent by cars O to 4 years old, 35 percent by cars 5 to 9 years old, and 25 percent by cars 10 years old and older. Call this the "low" car sales case. If VMT are held constant at the 1980 level, fuel consumption under the base case would be up to 0.3 MMB/D (or nearly 20 Percent) *lower* than fuel consumption in the "low" car sales case in 1990, everything else being equal. And cumulative oil savings could be over 1 billion bbl during the period 1981-2000. The base case, however, probably would be accompanied by higher VMT than the "low" sales case, and much of this savings could be lost.

Total projected oil savings are bracketed by the curves **in figure 11. These show the fuel conserved relative to the 1985** baseline case of new-car efficiencies of 30 mpg between 1985 and 2010. Clearly, the high-estimate technology scenario, accompanied by a continuing shift toward smaller cars, leads to large fuel savings. By 2010–when virtually the full benefit of fuel savings from **cars sold in the period 1985-2000** would be realized–the cumulative savings (relative to **a 30-mpg fleet) could be as high as 10 billion bbl of oil equivalent. This is equivalent to 6 years sup**ply of passenger-car fuel at the 1980 rate of consumption. The fuel **economy increases expected between now and 1985 would add about** 14 billion bbl to this cumulative savings between now and 2010 (relative to 1980 fuel consumption). Thus, between now and 2010, the total savings possible is about 24 billion bbl relative to 1980 passenger-car fuel consumption–an amount about equal to proven U.S. oil reserves, which were 26.5 billion bbl as of 1980.[19]

Substitution of Electric Vehicles

The estimates above are based on a passenger-car fleet for which energy comes from a fuel carried onboard—e.g., gasoline or diesel fuel. In the

[19]*World Petroleum Availability 1980-2000*— *Technical Memorandum, OTA-TM-5* **(Washington, D. C.: U.S. Congress, Office of Technology Assessment, October 1980.)**

Figure II.—Cumulative Oil Savings From Increased Automobile Fuel Efficiency Relative to 30 MPG in 1985, No Change Thereafter
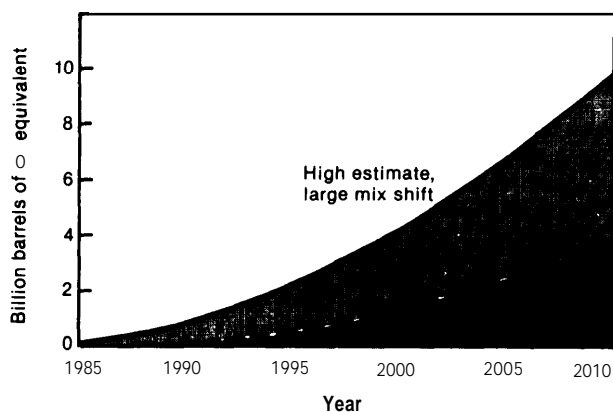
SOURCE: Office of Technology Assessment.

"Battery-Electric and Hybrid Vehicles" section, the prospects for EVs were briefly discussed, with the conclusion that major improvements in battery performance were necessary before EVs (or hybrids) would be practical in any but very specialized applications. If, however, these improvements are achieved—or if acute shortages of transportation fuels occur in the future—EVs might be sold in sufficiently large numbers to affect petroleum consumption.

The result would be to replace some of the petroleum consumed in the transportation sector by electric power generation. To the extent that this electricity was produced from nonpetroleum fuels–e.g., natural gas, coal, nuclear–the cumulative oil savings shown in figure 10 would increase (see app. 56). Table 28 illustrates the results for a highly optimistic level of EV substitution. Note that this again is *not* a prediction; substantial penetration by electric and/or hybrid vehicles **(EHVs) before the** end of the century is unlikely, and doubtful even thereafter. The table simply shows what might happen if battery improvements occur more rapidly than OTA expects, **or** if other factors combine to increase the attractiveness of **EHVs. Table 28 assumes that EHVs represent 5 percent of the total U.S. passenger-car fleet by 2000, and 20 percent by 2010. This** would require **EHV production and sales at** levels of several million per year during the last few years of the century.

Table 28 shows that penetration of EHVs at high enough rates could begin to replace meaningful volumes (14 percent) of transportation fuels dur-

Table 28.—Effects of Substituting Electric Vehicles[a]

	Composition of passenger-car fleet (million)		Passenger-car fuel consumed or replaced (MMBID)	
	2000	2010	2000	2010
Conventional cars	133	124	1.7	1.4
EVs	7	31	0.04	0.2
Percent EVs	5	20	—	—
Percent fuel consumption replaced.	—	—	2	14

[a]If battery Improvements occur more rapidly than OTA expects, or if other factors combine to increase the attractiveness of electric vehicles.

SOURCE: Office of Technology Assessment.

ing the first decade of the next century. Nonetheless, the savings in petroleum would be relatively small in absolute terms–because EHVs are best suited as replacements for small cars which already get good mileage.

Comparing the estimated fuel savings in table 28–only **0.2** MM B/D even for optimistic assumptions of EHV penetration—with the fuel-consumption trends projected in figure 9, demonstrates that improvements in automobile technology, particularly if combined with more rapid mix shifts toward smaller cars, offer much greater potential. Thus, the primary apparent advantage of EVs during the next 30 years is that they would not depend on petroleum supplies—an important factor if severe absolute shortages develop–rather than any potential for *saving* petroleum.

Fuel Use by Other Transportation Modes

Thus far, the discussion of fuel consumption has been restricted to passenger cars, although, as pointed out earlier, many light trucks—i.e., vans and pickups—are used primarily for passenger travel. In addition, medium and heavy trucks, buses, motorcycles, and airplanes–plus rail and marine transportation and military operations— consume petroleum-based fuels. All of these transportation modes depend predominately on heat engines for power, although SI engines are not so widely used as in passenger cars. Diesels have already replaced SI engines in almost all heavy trucks, and rates of installation in medium-duty trucks are going up rapidly. Diesels are also common in rail and marine applications, although some large ships rely on gas turbines or steam power. Commercial aircraft are generally powered by turbine engines.

Table 29 summarizes the projected oil consumption for transportation between 1980 and 2000. The projections for automobiles are derived in this chapter, while those for other transportation modes are taken from the "market trend" base case in a recent Department of Transportation study.[20] The projections for fuel consumption by trucks in table 29 assume that many of the technological improvements discussed above for passenger cars will also be applicable to light trucks. However, the specific technologies discussed elsewhere in this chapter are more generally appropriate to pickup trucks and vans than to medium and heavy trucks.

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[20]J. **K. Pollard, et al., "Transportation Energy Outlook: 1985-2000," Transportation Systems Center, U.S. Department of Transportation; DOT-TSC-RS-1 12-55-81-6, September 1981.**

Table 29.-Projected Petroleum-Based Fuel Use for Transportation

Mode	1980[a] MMB/D[b]	1980[a] Percent	1990[a] MMB/D[b]	1990[a] Percent	2000[a] MMB/D[b]	2000[a] Percent
Passenger car	4.3	49	2.4-2.9	35	1.3-2.1	23
Light trucks	1.1	13	0.9	12	0.8	11
Other trucks.	1.1	13	1.2	16	1.4	19
Other highway (buses, motorcycles, etc.)	0.1	1	0.2	3	0.2	3
Total highway	6.6	75[c]	4.7-5.2	65[c]	3.7-4.5	5 5[c]
Air	0.8	9	1.1	14	1.5	20
Marine.	0.7	8	0.8	10	0.9	12
Rail	0.3	3	0.4	5	0.4	5
Pipelines [d]	0.1		0.1	1	0.1	1
Military Operation	0.3	3	0.3	4	0.4	5
Total nonhighway	2.2	25[c]	2.7	35[c]	3.3	45[c]
Total	8.8	100	7.4-7.9	100	7.0-7.8	100

[a]All fuel consumption numbers, except for passenger cars, from J. K. Pollard, C. T. Phillips, R. C. Ricci, and N. Rosenberg, "Transportation Energy Outlook: 1985-2000," U.S. Department of Transportation, Transportation Systems Center, Cambridge, Mass., DOT-TSC-RS-112-55-81-6, September 1981. Passenger-car fuel consumption from this study.
[b]1B -5.9 MMBtu.
[c]Sums may not agree due to round-off errors.
[d]Does not include natural gas.

SOURCE: Office of Technology Assessment.

Some of the fuel economy gains for other transportation modes—as for passenger cars—will be offset by growth in miles traveled. Annual growth rates of 1 to 3 percent per year are expected for most modes of transport, although sales of light trucks have recently dropped to such an extent that mileage traveled by such vehicles may decrease in the years ahead. **In** total, fuel consumed for transportation is projected to decline from 8.8 MMB/D in 1980 to the range of 7 to 8 MMB/D by 2000, and then to rise slowly as diminishing returns set in.

Because of the differing growth rates for the various transportation modes and the differing magnitudes of the fuel economy improvements expected, the distribution of fuel use by mode will change. Passenger cars now account for half of all the fuel used in transportation. Their share will decrease to about 25 percent by the early part of the next century. Medium and heavy trucks currently consume 12 percent of all transportation fuel, a figure that could rise to 20 **percent** by 2000. Likewise, the percentage of transport fuels used by aircraft could nearly double.

COSTS OF INCREASED FUEL EFFICIENCY

Overview

Automobile manufacturers spend for many purposes–R&D, investment in plant and equipment, labor, materials, marketing, and administration. How much a particular manufacturer spends depends on the firm's financial capabilities, the rate of technology change, initial characteristics of the product line, and the state of existing manufacturing facilities.

R&D on vehicle designs and manufacturing processes is an important spending area. Development—on which most R&D money is spent, research expenditures being small by comparison —creates new product designs and production methods. Growth in R&D activity, required to support rapid changes in vehicle design, will raise both the total costs of automobile production and the proportion of development and other preproduction expenses.

In 1980, the four major domestic manufacturers spent almost $4.25 billion (1980 dollars) on R&D. For individual firms, this spending amounted to 2 to 5 percent of sales revenues. in addition, major parts and equipment suppliers spent about $293 million on automotive R&Din 1980. Together, major automobile manufacturers and suppliers spent over $4.5 billion on R&D for automobiles and other vehicles.[21]

Capital investment levels are even greater. These expenditures, which go hand-in-hand with design and development activities, are the largest single category of spending in automobile manufacturing. Major categories of capital goods include factory structures, production equipment such as machine tools and transfer lines, and a wide variety of special tools such as dies, jigs, and fixtures.

Manufacturers today are making investments to improve product quality, as well as increase productivity and cut costs. Flexible manufacturing is also becoming an increasingly attractive investment. Such sophisticated facilities are relative-**ly** expensive but may yield low operating costs and other long-term benefits. General Motors (GM), **Ford,** and Chrysler spent $10.8 billion (1980 dollars) on property, plant, equipment, and special tooling in 1980.22

Financing is an important aspect of capital investment. Historically, the automobile industry has financed capital programs with retained earnings, except during recessions when low sales generated inadequate revenues. Several current, and possibly enduring, factors—declining profitability, high inflation, slow market growth, market volatility, and consumer resistance to real price increases—have eroded manufacturers' ability to finance major capital programs from earnings (or by issuing stock), leading them to borrow funds

[21]" **R&D Scoreboard: 1979," Business Week, July 7, 1980; "R&D Scoreboard: 1980, " Business Week, July 6, 1981.**

[22]**Annual Reports for 1980.**

and therefore to face potentially higher costs of capital. GM and Ford each borrowed over $1 billion during 1980; they may together borrow as much as $5 billion by the mid-1980's.[23]

Although domestic manufacturers have recently borrowed from foreign and other nontraditional sources, they are able to borrow only a limited portion of their capital needs (at acceptable interest rates). Borrowing in the United States has recently become more costly to automobile manufacturers because their bond ratings have been lowered, in recognition of the low profitability, high spending levels, and high risks that characterize today's auto market. Consequently, they are obtaining cash by restructuring their physical and financial operations (e.g., by selling assets and changing the handling of accounts receivable), engaging in joint ventures, and selling tax credits (under Economic Recovery Tax Act of 1981 leasing rules).

Automotive fuel economy improvement affects other costs as well, although not to the same extent that it affects R&D and capital investment, Costs for labor and materials depend on vehicle design and on production volumes and processes. For example, automated equipment reduces labor content; small cars require less material; and lighter body parts and more efficient engines may require new, relatively expensive materials (high-strength steels, aluminum alloys) and processes (heat treatments, longer weld cycles, a greater number of forming operations, slower machining). Reductions in the amounts of labor and materials used per car help offset inflationary and real increases in their costs. Labor costs, however, are slow to change in the short term because they are subject to union negotiations, and because contractual provisions constrain layoffs and require compensation payments.

Finally, spending on marketing and administration is not directly related to technological change or to production; although these expenses may be cut back to facilitate spending in other areas. During 1980, for example, auto manufacturers made large cuts in white collar staffs to lower ad-

ministrative costs. However, marketing activities may increase because of heightened competition or the introduction of new products.

The remainder of this chapter focuses on capital costs, because they are the critical component of the overall costs of changing automobile designs. On **a per car basis,** however, labor and materials costs will remain higher than capital costs because of the ways different types of costs are allocated. The costs of capital goods (including financing) are recovered throughout their service life in vehicle prices. Since capital goods are used to produce many vehicles over many years (at least 30 years for plants, 12 years for much production equipment, and 3 to 5 years for special tooling), each vehicle bears a relatively small percentage of the costs of capital to produce it. In contrast, labor services and materials are effectively bought to manufacture each car.

Relative to other manufacturing costs, capital costs are expected **to** undergo the greatest percentage increase as manufacturers increase their output of fuel-efficient vehicles. Moreover, capital costs are becoming proportionately greater because capital goods are being purchased at faster rates and at higher real prices than historically, and because automotive production is becoming more capital-intensive as automation proceeds— i.e., more capital equipment is being used to produce automobiles relative to labor, materials, and other inputs. Consequently, capital costs will have an especially pronounced influence on the financial health of automobile manufacturers over the next two decades.

Investments to Raise Fuel Economy Technology-Specific Costs

Table 30 presents capital cost estimates prepared by OTA for the technologies described earlier in this chapter, based on discussions with industry analysts and the most recently published analyses. However, they draw on the experience and expectations of the mid and late 1970's, when limited consumer demand for fuel economy led manufacturers to make conservative projections of vehicle design changes and high projections of costs. Because of recent surges in the demand for fuel economy and small cars, manufacturers now expect to make substantial im-

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[23]Also see''Producing More **Fuel-Efficient Automobiles: A Cost-** ly **Proposition, " op. cit.**

Table 30.—Post-1985 Automotive Capital Cost Estimates

	$M/500,000 units	Associated costs
Platform change		
Weight reduction, redesign	500-1,000	R&D[a], redesign
Material substitution	100-400	R&Da, materials, labor
Engine change		
Improved Sib, diesel	50-250	R&D[a], redesign
New Sib, diesel, DISC[c]	400-700	
Transmission change		
Improve contemporary drivetrains.	100-400	R&D[a], redesign
New drivetrains—CVT[d], energy storage, engine on-off.	500-700	R&D[a], redesign

[a]Capital costs for accessory and lubricant Improvements and aerodynamic and rolling resistance reductions are not Included separately. They may in total cost about $50M/500,000, an amount within the range of error Implied by the above estimates. Note: aerodynamic improvements will be carried out with weight-reducing design changes; lubricant end tire changes are already being made by suppliers and may continue as a regular aspect of their businesses; and some accessory Improvements . are made regularly and as accompaniments to engine redesigns.
[b]Spark ignition.
[c]Direct injection stratified charge.
[d]Continuously variable transmission.

SOURCE: Office of Technology Assessment.

provements in fuel economy by the mid-1980's by accelerating technological change schedules and by increasing the proportion of small cars in the sales mix.

Note that increasing production volume for existing models is much cheaper than introducing new models; U.S. manufacturers could probably double their output of many existing models. The costs of design changes in the post-1985 period now seem even more uncertain, because earlier achievements will leave fewer and generally more costly options available.

Projecting costs for specific design changes is difficult, for several reasons. First, the redesign of any one vehicle component or subsystem often necessitates related changes elsewhere. Second, such changes may require new production processes. Third, actual costs to individual manufacturers are technology-specific and sensitive to several factors—technological development, production volume, vertical integration, the rate at which changes penetrate the fleet, and available manufacturing facilities. These factors are discussed below.

Technological Development.–Many technologies are inherently expensive due to materials requirements or complexity of design or manufacture. The diesel engine for passenger cars is a good example. Over time, experience with a new technology may lead to some cost reduction.

Production Volume.–Costs vary with production volume because equipment and processes are designed such that average product cost is lowest once a threshold production volume is achieved.[24] Because this minimum volume or scale grows as the production process becomes more highly automated, the rising capital intensiveness of automobile production increases the sensitivity of unit costs to production volume. Operating costs (comprised of labor, materials, and allocated marketing and administration costs) per unit are sensitive to production volume in the short term. For example, Ford's operating costs per dollar of sales were estimated to be under $0.90 in the first **quarter** of 1979, but subsequent sales declines brought them close to $1.05 by the fourth quarter of 1980.[25]

The cost estimates in table 30 assume uniform 500,000-unit capacities. * Cost estimates for uniform or optimal capacity levels provide a better measure for spending levels for the industry as a whole than for individual manufacturers because individual firms acquire different levels of capacity at different costs according to their finan-

[24]See K. Bhasker, "The Future of the World Motor Industry" (New York: Nichols Publishing Co., 1980.) The optimum production volumes may change with manufacturing technology, however.
[25]" Ford's Financial Hurdle: Finding Money is Harder and Harder," Business Week, February 1981.
*This procedure was aiso employed in the Mellon Institute study (Ref. 32) which drew on data provided by automobile manufacturers.

cial ability, sales volume, and technological options. The costs of acquiring more or less than optimal capacity, however, are not linearly related to the level of capacity.

Vertical Integration.—Vertical integration refers to the degree to which a manufacturer is self-sufficient in production or distribution. integration can reduce costs in two ways: 1) by eliminating activities and costs associated with the transfer of goods between suppliers and distributors (dealers), and the automakers themselves; and 2) by enabling manufacturers to optimize the flow of production and distribution. Major U.S. automobile manufacturers are highly integrated compared with firms in many other industries, although they are much less integrated than oil companies. Various U.S. automobile firms make steel, glass, electronic components, and robots, but overall they buy about ha lf of their materials and other supplies. GM's greater vertical integration relative to other U.S. automobile manufacturers is one reason for its lower manufacturing costs. The high effective degree of vertical integration among Japanese auto manufacturers (over 80 percent for some firms) helps to make auto production in Japan cheaper than in the United States. *

Rate of Change.–The rate at which new technology is incorporated in automobiles influences cost in three important ways. First, the faster a design is implemented, the shorter are the product development, product and process engineering schedules, and the less likely is production to be at minimum cost, given scale. Second, increasing the rate of technological change raises the number and magnitude of purchases from suppliers. Third, a faster rate of change can make facilities and processes technologically obsolete, necessitating investments in replacements before original investments are recovered.

Available Facilities.—Opportunities for manufacturers to redesign their product lines are shaped by the characteristics of their base vehicles and existing production facilities. The technological scenarios described at the beginning of

this chapter illustrate how paths of change may differ.

Estimates of manufacturing costs require evaluation of the requirements for implementing each combination of new technologies. Investment by different manufacturers to produce the same vehicle will differ because their initial facilities and vehicle designs provide different bases for change, and because manufacturers have choices in the timing and extent of major facility renovations, in balancing plant renovation and new construction, and the selection of new production equipment—e.g., degree of automation. Different production bases make rapid change more costly for some manufacturers than for others.

The variability in actual facilities costs is illustrated by recent projects associated with new vehicle designs. Chrysler spent over $50 million to renovate its Newark assembly plant to produce 1,120 K-cars per day. * Chrysler made similar alterations to its Jefferson Avenue (Detroit) assembly plant to enable K-car production at the same rate as at the Newark plant, but at a cost of$100 million. GM plans to spend $300 million to $500 million to build a new Cadillac assembly plant (replacing two old ones) on the Chrysler Dodge Main site in Michigan. The differences in these spending levels reflect different starting points and differing objectives. Since automation, quality control, and nonproduction aspects of the above projects contribute to other goals in addition to higher fuel economy, these examples illustrate how difficult it is to infer the specific costs of investments *to* raise fuel economy.

New Car and Fleet Investments

The incremental investments manufacturers make to raise automobile fuel efficiency **will affect the costs of producing new cars and new-car fleets.** To gage **the effect of changing automotive technology on industry investment requirements, the costs of capacity associated with the high- and low-estimate scenarios were estimated**

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*These conditions reflect peculiarly close relationships between Japanese manufacturer and supplier firms, even in the absence of formal linkages.

*The project entailed new plant layout; body shop *renovation;* conveyor system replacement and rearrangement; assembly tooling replacement; installation of automatic and computerized machine welding, transfer, and framing equipment; installation of new painting, front-end alignment, trim and cushion assembly equipment and additional quality control systems.

by weighting and adding the costs of specific changes. This procedure produces crude estimates of the investments necessary to produce cars at fuel efficiencies projected in the scenarios. * Table 31 presents investment projections by scenario and by 5-year periods, and tables 32-34 present the derivation of table 31 in somewhat more detail.

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*Assuming that each technology is applied across the fleet at efficient volume, the calculations can be performed on a per-500,000 unit basis and scaled up or down to determine overall or implied per unit investments. The average investment to produce each size class in each period with projected technological characteristics may be calculated by weighing the cost of each technology (table 30) by its proportion of application and summing the weighted investments.

Adding the costs of specific technologies taken separately—for which cost data are available—is an imprecise way of estimating the costs of technology combinations embodied in new automobiles and fleets, because it does not capture the costs of implementing changes together. Very accurate investment estimates can be made by evaluating for specific new automobile designs the plant-by-plant changes in costs (for everything from property and construction to engineering and equipment to taxes), accounting for various economies (concurrent and sequentially introduced technologies may share plant, equipment, even special tooling) and extra costs for minor changes to the car during production.

Table 31.—Summary of Investment Requirements Associated With Increased Fuel Efficiency

Year	Units	High estimate[a]			Low estimate[a]		
		Large	Medium	Small	Large	Medium	Small
1985-90	$Mil./5OO,OOO	900-1,740	820-1,660	780-1,600	490-1,000	480-1,000	450-1,000
	$/car	180-350	160-330	150-320	100-200	100-200	90-200
1990-95	$Mil./5OO,OOO	570-1,100	570-1,100	610-1,200	520-940	520-930	500-900
	$/car	110-230	110-230	120-240	100-190	100-190	100-180
1995-2000	$Mil./5OO,OOO	350-950	370-980	350-050	480-860	520-930	500-900
	$/car	70-190	70-200	70-190	100-170	100-190	100-180

[a]**See table** 23 and 24 for definitions of these scenarios.

SOURCE: Office of Technology Assessment.

Table 32.—Average Capital Investments Associated With Increased Fuel Efficiency by Car Size and by Scenario (1985=90)

	Percent of production facilities that incorporate new technologies or are redesigned					
	High estimate			Low estimate		
	Large	Medium	Small	Large	Medium	Small
Engines						
SIE [a] $50-250M/500,000 30	70	95	60	80	100
Prechambe[b] $400-700 M/500,000. 15	—	5	15	10	—
Open chamber[c] $400-700M/500,000 30	20	—			
Transmissions						
Four-speed auto and TCLU[d]						
$300-500M/500,00 70	70	70	50	50	50
Platform						
Various[e] $500-1,000 M/500,000 100	100	100	50	50	50
Capital costs for technology changes weighted average)						
Total $M/500,000. . . . . $905-1,740	$825-1,665	$778-1,623	$490-1,005	$480-1,020	$450-1,000
Per car (total÷500,000÷10)f $181-348	$165-333	$156-325	$98-201	$96-204	$90-200

[a]%ark-ignition engine.
[b]Prechamber diesel.
[c]Open chamber diesel or open chamber stratified charge.
[d]Four-speed automatic with torque converter lockup.
[e]Weight reduction, material substitution, aerodynamic and rolling resistance reductions, improved lubricants end assessories,
[f]Vehicle change investments are divided by 10 to approximate amortization practices. Forty percent of capital spending goes for plant (30 year) and equipment (12 years), which may together be summarized as "facilities" and amortized over 15 years (Ford Motor Co. interview) 0.4x3+0.6x 15 = 10.2 or about 10 years.

SOURCE: Office of Technology Assessment.

**Table 33.—Average Capital Investments Associated With Increased
Fuel Efficiency by Car Size and by Scenario (1990-95)**

| | Percent of production facilities that incorporate new technologies or are redesigned | | | | | |
| | High estimate | | | Low estimate | | |
	Large	Medium	Small	Large	Medium	Small
Engines						
SIE $400-700 M/500,000	15	25	35	25	35	50
Prechamber $400-700 M/500,000 . . . . –	—	—	30	20	—	
Open chamber $400-700 M/500,000 40	30	30				
Transmissions						
CVT, four-speed auto and TCLU						
$500 -700 M/500,00 35	35	35	50	50	50	
Engine on-off $500-700 M/500,000 ... , ... 15	15	15				
Platform						
Various $100-400 M/500,000	100	100	100	50	50	50
Capital costs for technology changes						
Total $M/500,000 . . . . $570-1,135	$570-1,135	$610-1,205	$520-935	$520-935	$500-900	
Per car(total =500,000 +10). . . . . $114-227 -			$104-187	$104-187	$100-180	

SOURCE: Office of Technology Assessment.

**Table 34.—Average Capital Investments Associated With Increased
Fuel Efficiency by Car Size and by Scenario (1995.2000)**

| | Percent of production facilities that incorporate new technologies or are redesigned | | | | | |
| | High estimate | | | Low estimate | | |
	Large	Medium	Small	Large	Medium	Small
Engines						
SIE $400-700 M/500,000	15	15	35	15	25	10
Open chamber $400-700 M/500,000	35	40	15	30	30	40
Transmissions						
CVT improved $100-400 M/500,00	50	50	50			
CVT $500-700 M/500,000	—	—	—	35	35	35
Engine on-off $500-700M/500,000	—	—	—	15	15	15
Platform						
Various $100-400 M/500,000	100	100	100	*50*	50	50
Capita/ costs for technology changes						
Total $M/500,000	$350-950	$375-985	$350-950	$480-865	$520-935	$500-900
Per car (total÷500,000÷ 10).	$70-190	$74-197	$70-190	$96-173	$104-187	$100-180

SOURCE: Office of Technology Assessment.

The Transportation Systems Center of the U.S. Department of Transportation, for example, has developed a "surrogate plant" methodology to do this. The accuracy of this approach is based on detailed consideration of vehicle designs and the corresponding equipment and plant needs. The methodology requires specific projections of engineering changes that are beyond the scope of this report, and speculative for the 1990's.

Note that investment figures presented here apply only to investments required to raise the fuel economy of cars sold in the United States. Total capital spending reported by U.S. manufac-

turers also includes investment in nonautomobile projects (such as truck and military equipment production), investments in foreign subsidiaries, and spending for normal replacement of worn-out capital and for capacity improvement and expansion.

Note also that not all of a given investment may be associated with fuel economy improvement. For example, engines, transmissions, and car bodies are redesigned periodically. Changes of this sort cannot always be distinguished from those made for increased fuel efficiency, so the full cost of the investments shown in table 31 should not be allocated solely to fuel economy improvements.

The difficulty of allocating costs when a single investment produces several distinct results is a well-known problem of accounting,[26] and there is no fully satisfactory method for making the allocations. For the purposes of the fuel savings cost analysis in the next sections, it is assumed that the percentages shown in table 35 represent the share of investment costs attributable to increases in fuel economy. Engine and body redesigns are made for many reasons other than fuel efficiency. **On** the other hand, most of the advanced materials substitution (to plastics and aluminum)

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[26]AL.Thomas,''TheAllocation **Problem in Financial Account-ing Theory" (Sarasota, Fla.: American Accounting Association, 1969), pp. 41-57, and A. L. Thomas, "The Allocation Problem: Part Two" (Sarasoto,Fla.: American Accounting Association, 1974.)**

assumed in the scenarios, or automatic engine cutoff, probably would not be incorporated into cars by 2000 without the impetus **for increased fuel efficiency. Advanced transmissions represent an intermediate case between these extremes.**

The total capital investment associated with the production of fleets of given size mix is calculated by taking an appropriately weighted sum of investments by size class. Assuming that U.S. new-car sales average 11.5 million units in 1985-90, 11.7 million units in 1990-95, and 12.1 million units in 1995-2000 (conforming to growth rates projected earlier in this chapter); and assuming that imports throughout the 1985-2000 period average 25 percent of all sales (near recent levels), following the high-estimate scenario for the 15-year period may require $30 billion to $70 billion in investments and R&D expenditures. Following the low-estimate scenario may require about $25 billion to $50 billion (see table 36). if new-car sales are lower due to continued recession and consumers' stagnant real disposable income, then the investments would be proportionately smaller. For example, if domestic sales remain at 8 million vehicles per year (6 million domestically produced) between 1985 and 2000, then capital investments would be about two-thirds as large as shown in table 36 (but R&D costs could remain

Table 35.—Percentage of Capital Investments Allocated to Fuel Efficiency

Category	Percentage of investment allocated to fuel efficiency
Engine.	50
Transmission:	
CVT, four- and five-speed auto and TCLV	75
Energy storage and engine on-off	100
Platform:	
Weight reduction (body redesign)	50
Materials substitution	100
Composite of all efficiency related investments:	
1985-90	55-85
1990-95	70-80
1995-2000	65-75

SOURCE: Office of Technology Assessment.

Table 36—Total Domestic Capital investments for Changes Associated With Increased Fuel Efficiency[a] (billion 1980 dollars)

Time of investment	High estimate[b]	Low estimate[b]
High car sales[a]		
1985-90	14-29	8-17
1990-95	10-20	9-16
1995-2000	7-18	916
Total.	31-67	26-49
Low car sales		
1985-90	10-20	6-12
1990-95	7-14	6-11
1995-2000	4-12	6-11
Total	21-46	18-34

assumptions about car sales:
High car sales
1985-90 . . . **11.5 million cars/yr**
1990-05 . . . . . . **11.7 million cars/yr**
1995-2000. . . . **12.1 million cars/yr**

Low car sales
1985-2000. . . . **8 million cars/yr**
Estimates also assume that imports average 25 percent of **total car sales between 1985 and 2000.**
[b]Within the uncertainties, the Investment requirements are the same for all three sales-mix scenarios.

SOURCE: Office of Technology Assessment.

the same). If this happens, total investments plus R&D would be reduced by about 25 percent below those for the high car sales case.

The greater investments (per vehicle) associated with the high-estimate scenario reflect the fact that the scenario contains more extensive changes more often than the low-estimate scenario. In either case, however, there is no significant difference in the total investment for increased fuel efficiency for the different size-mix scenarios, since the rate of capital turnover for increased fuel efficiency is probably adequate to accommodate the mix shifts. *

OTA estimates of cumulative investments imply that manufacturers would make capital investments of $2 billion to $5 billion per year (1980 dollars) over about 15 years to implement the high-estimate scenario and about $2 billion to $3 billion per year to implement the low-estimate scenario in the case of high car sales. The corresponding figures would be about $1.5 billion to $3 billion and $1billion to $2 billion, respectively, for low car sales.

Actual added capital spending levels by manufacturers are likely to be lower than indicated because some investments in technologies to raise fuel economy will take the place of investments in more conventional technologies that would normally be made as plant and equipment wear out. In fact, deducting the cost of changes that would have been made under normal circumstances,** but are obviated by or could be incorporated in the investments shown in tables **32-34,** could reduce the added investment cost of implementing the scenarios by two-thirds in the high estimate and by about 80 percent in the low estimate, leading to capital investments averaging $0.3 billion to $0.7 billion per year for the low estimate (high car sales) and **$0.6** billion to $1.5 billion per year for the high estimate (high car sales) above "normal. "

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*On the average, over 50 percent of engines, transmissions, and bodies are being redesigned during each 5-year period for increased fuel efficiency, whereas the mix shift requires 10 to 20 percent change during each 5-year period.

**Assuming "normal" capital turnover is: engines improved after 6 years, on average, redesigned after 12 years; transmissions same as engines; body redesigned every 7.5 years; no advanced materials substitution.

Spending by the automakers will be reduced to the extent that they buy rather than make various items; to the extent that U.S. suppliers provide purchased items, the total investment levels can be viewed as spending estimates for U.S. automakers and suppliers together. However, joint ventures with foreign firms, erection of foreign plants with foreign government aid and relatively labor-intensive designs, and purchases of parts and knocked-down vehicle kits from overseas would all lower investment costs to U.S. firms. So would an increase in import penetration. Finally, note that future levels of normal capital spending, however they are determined, may be higher than past levels if competition from foreign manufacturers makes it "normal" frequently spend to improve fuel economy and to modernize facilities.

Fuel Savings Costs

To compare the costs and gains of saving fuel by raising automobile fuel economy with the costs and gains through other means, it is useful to express costs in terms of a common measure such as dollars per quantity of oil (gallons or barrels-per-day) saved. To measure the total dollars per quantity of oil saved implied by raising fuel efficiency requires estimating changes in variable (labor and materials), fixed capital and R&D costs.

OTA was unable to obtain or develop reliable variable cost figures for technologies discussed in this report, because information about variable costs, which vary considerably between companies, is proprietary and speculative for the 1990's. Four general observations about variable costs of raising fuel **economy can be made:** First, implementing some new technologies, including certain weight-reduction measures (e.g., smaller engines and body frames), will lower variable costs by reducing labor and materials requirements. Second, automation will lower labor requirements. Third, using some new technologies, such as four- and five-speed transmissions and alternative engines, will raise variable costs because they are inherently more complex than conventional technologies. Fourth, use of new materials will raise variable costs. The net change in variable costs is uncertain and will depend heavily on basic materials costs and the success

of **adapting the new designs to mass production. Note that variable** costs have been about three times the level of fixed costs for the average car or light truck.

Based on the percentages shown **in table 35,** however, table 37 shows the capital investment attributable to increased fuel efficiency per gallon of gasoline equivalent saved, assuming the average car is driven 100,000 miles and the average service life of the investment is 10 years. In all cases, the investment cost is less than $1.00 per gallon saved. If, however, accelerated capital turnover reduces the useful service life of the investment to 5 years, the costs would be twice those shown in table 37. Conversely, if automobiles are kept longer and driven further in the future, then the cost per gallon is reduced. For example, if cars are driven 130,000 miles over their lifetime, on the average, the costs would be 75 percent of those shown in table 37.

The final cost category considered here is the product development cost. Although it is difficult to make detailed predictions of the costs of development, U.S. automobile manufacturers spent from **40** to 60 percent **as** much on R&D (mostly

development) during the 1970's as they spent on capital investments.[27] During 1978 and 1979, R&D averaged about **40** percent of capital investments.

In order to compare the investments for increased fuel efficiency in automobiles with those for synfuels, it is convenient to express them as the investment cost attributable to fuel efficiency plus the associated R&D expenditures per barrel per day oil equivalent saved by these investments. Assuming that development expenditures are 40 percent of capital investment, the costs in table 37 can be converted to the investments shown in table 38 for individual cars and fleet averages between 1985 and 2000. The combined R&D and capital costs appear to increase somewhat from the 1985-90 period to the 1990-95 period. However, technical advances by the early 1990's could prevent further increases during the late 1990's.

[27]G.Kulp,D.B.Shonka,and M. C. Halcomb, **"Transportation Energy Conservation Data Book: Edition 5,"** Oak Ridge National Laboratory, ORNL-5765, November 1981.

Table 37.—Estimated Capital Investment Allocated to Fuel Efficiency per Gallon of Fuel Saved

	High estimate			Low estimate		
	Car size:			Car size:		
	Large	Medium	Small	Large	Medium	Small
1985						
Mpg 27		39	48	23	35	45
1990						
Mpg 37		51	62	28		52
Gallons saved/yr[a]	910	550	430	705	380	270
Investment ($/car)[b] 100-190		90-180	90-180	60-110	60-110	50-110
Dollars per gallon[c] 0.11-0.21		0.17-0.34	0,21-0.42	0.084,16	0.15-0.30	0.19-0.41
1895						
Mpg 43		61		31	45	57
Gallons saved/yr[a] 340			240	310	200	150
Investment ($/car)[b] 80-180		80-180	90-180	70-130	70-130	70-130
Dollars per gallon[c] 0.24-0.51		0.29-0.60	0.37-0.77	0.22-0.42	0,35-0.67	0.44-0.83
2000						
Mpg 50			85	35	50	65
Gallons saved/yr[a]	260	210	150	260	200	190
Investment ($/car)[b] 50-150		50-150	50-150	70-130	70-140	70-140
Dollars per gallon[c] 0.18-0.56		0.24-0.71	0.33-0.99	0.27-0.50	0.36-0.68	0.36-0.68

[a]**Fuel consumption** of car relative to fuel consumption of comparable car 5 years earlier. Assumes 100,000 miles driven over life of car and on-the-road fuel efficiency 10 percent less than the EPA rated mpg shown.
[b]The investment attributed to fuel efficiency assuming an average life of 10 yeara for the investment. Also assumes production at rated plant capacity during the 10 years. Does not include R&D costs, which would add about 40 percent to the cost.
cThe investment per car divided by the fuel saved over the life of the car.

SOURCE: Office of Technology Assessment.

Table 36.-Capital Investment Attributed to Increased Fuel Efficiency Plus Associated Development Costs per Barrel/Day of Fuel Saved

Car size	New-car fuel efficiency at end of time period[a] (mpg)	Capital investment plus associated development costs (thousand 1980$ per B/D oil equivalent fuel saved)[b]
1985-90		
Large.........	28-37	19-51
Medium	41-51	35-81
Small.........	52-62	47-1oo
Average A[c]....	38-48	21-57[d]
Averge B[c].....	43-53	21-60[d]
1990-95		
Large.........	31-43	53-120
Medium	45-61	69-160
Small.........	57-74	89-200
Average A[c]....	43-59	58-120[d]
Average B[c]....	49-65	64-140[d]
1995-2000		
Large.........	34-49	44-130
Medium	50-71	57-170
Small	65-84	78-240
Average A[c]....	51-70	48-150d
Average B[c]....	58-78	50-150[d]

[a]EPA rated 55/45 city/highway fuel efficiency of average car in each size class.
[b]Assumes development costs total 40 percent of capital investments and that a car is driven 10,000 miles per year on averge. A barrel of oil equivalent contains 5.9 MMBtu.
[c] Averages A and B are based on the moderate and large mix shift scenarios, respectively.
[d] Averages are calculated by dividing average investment fOr technological improvements by fuel savings for average carat end of time period relative to average car at beginning of time period. The resultant average cost per barrel par day is lower than a straight average of the investments for each car size because of mathematical differences in the methodology (I.e., average of ratios v. ratio of averages) and because extra fuel is saved due to demand shift to smaller cars. The averaging methodology used is more appropriated for comparisons with synfuels because it relates aggregate investments to aggregate fuel savings. It should be noted that the cost of adjusting to the shift in demand to smaller sized cars is not Included. Only those investments which increase the fuel efficiency of a given-size car are included. However, given the rate of capital turnover assumed for the scenarios, adjustments to the shift In demand probably can be accommodated within the investment costs shown.

SOURCE: Office of Technology Assessment.

Note that the costs and fuel savings benefit of improving fuel economy are incurred at different times by different parties. Manufacturer (and supplier) investments are made prior to production: 30 percent of capital spending occurs 12 to **24** months before first production, 65 percent occurs within the 12 months preceding production, and 5 percent occurs after production begins.[28] R&D costs may occur 5 to 7 years before first production. Fuel savings begin only after a vehicle is purchased, and they accrue over several years. Fuel savings benefit the consumer directly and the industry only indirectly.

[28]HarbridgeHouse, **Inc.,** *Energy Conservation and the Passenger* **Car:** *An Assessment of Existing Public Policy,* **Boston, July 1979.**

Consumer Costs

Automotive fuel economy improvements can affect costs to consumers through changes in real car purchase prices and changes in real costs of maintaining and servicing cars.

Prices

Trends in average car prices are easier to predict than trends in prices for specific car classes or models, because manufacturers have flexibility in pricing models and optional equipment. Real car prices (on which consumers base their expectations) have been relatively stable over the last 20 years (see fig. 12), although nominal car prices have risen steadily since the mid-1960's, because of general inflation. Labor and materials cost increases are not necessarily passed on to consumers. For example, the General Manufacturing Manager of GM's Fisher Body Division observed in a recent interview that although raw materials and labor costs have been rising about 11 to 12 percent annually, only 7 to 8 percent of those increases have been recovered through price, with improvements in productivity helping to control costs.

Figure 12.— Real and Nominal U.S. Car Prices, 1960-80
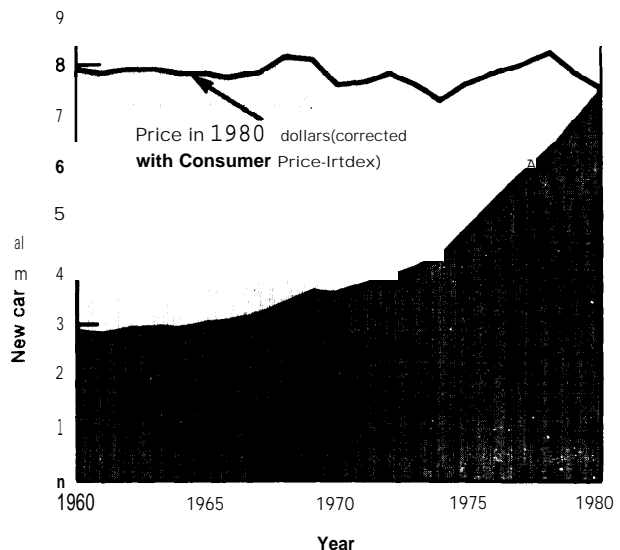
SOURCE: Bob Clukas, Bureau of Economic Analysis, U.S. Department of Commerce, private communication, 1981.

W/here expenses increase faster than prices, manufacturers can still make profits by charging higher prices for those options or car models for which consumer demand is relatively insensitive to price. This flexibility is eroded when large proportions of automotive costs increase due to rapid and extensive change. Some industry analysts expect that through the mid-1980's, large capital spending programs and real increases in labor and materials costs will lead to increases in real car prices of up to 2 percent per year (approximately half of which reflects capital costs); more rapid automotive change might lead to even greater increases.[29]

Two percent of today's average car price (about **$8,000)** is about $160, although prices of individual cars will rise by greater and lesser amounts. OTA's scenario analysis suggests that investment costs alone for 5-year periods could range fro-m $50 to $350 per car (assuming 10-year amortization periods for plant and equipment). The Congressional Budget Office (CBO), for comparison, concluded that average automobile production costs may increase by about $560 between 1985-95 **because** new technologies will cost that much (per car, on average) to implement.[30] These analyses may overstate the average amount of capital cost increase, because when new technologies replace old ones, the capital costs charged to old "technologies" should drop

out of the vehicle cost calculation (unless old equipment is made obsolete prematurely). Actual cost increases will also depend on changes in variable costs, as illustrated below.

Table 39 shows two plausible estimates of consumer costs (per gallon of fuel saved) for increased fuel efficiency, based on the analysis in this chapter. The lower costs are calculated assuming that labor and material (variable) costs are no higher for more fuel-efficient cars than for cars being produced in 1985.[31] The higher costs include variable cost increases that are twice as large as the capital charges associated with increasing fuel efficiency .32

Although the range varies from costs that are easily competitive with today's gasoline prices to levels much above those prices, OTA does not believe that future variable costs can be predicted with sufficient accuracy to warrant more detailed estimates of variable costs. Table 39 should therefore be viewed as illustrative; actual consumer costs will depend on many factors, including the success of new production technologies.

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[29]Maryann N. Keller, Status *Report: Automobile Monthly Vehic/e Market Review*, **Paine Webber Mitchell Hutchins, Inc., New York, February 1981.**
[30]Congressional Budget Office, *Fuel Economy Standards for* **Passenger Cars** *After 1985,* **1980.**

[31] **Richard L, Strom** botne, **Director, Office of Automotive Fuel Economy Standards, National Highway Traffic Safey Administration, U.S. Department of Transportation, private communication, 1981.**
[32]Richard H. Shackson and H. James Leach, **"Maintaining Automotive Mobility: Using Fuel Economy and Synthetic Fuels to Compete With OPEC Oil," Energy Productivity Center, Mellon Institute, Arlington, Va., Interim Report, Aug. 18, 1980. Variable cost changes were deduced from the estimates of capital investment and changes in consumer costs by assuming an annual capital charge of 15 percent of the investment and deducting this capital charge from the consumer cost estimate.**

Table 39.—Plausible Consumer Costs for Increased Automobile Fuel Efficiency Using Alternative Assumptions About Variable Cost Increase

| | | | Consumer cost[a] ($/gal gasoline saved) | |
Time period	Mix shift	Average fuel efficiency at end of time period (mpg)	Assuming no variable cost increase relative to 1985 variable costs of production	Assuming variable cost increase equal to twice the capital charges
1985-90	Moderate	38-48		
	Large	43-53	0.15-0.40[a]	0.40-1 lob
1990-95	Moderate	43-59		
	Large	49-65	0.35-0.85[b]	1.10-2.60[b]
1995-2000. . . .	Moderate	51-70		
	Large	58-78	0.30-0.95[b]	0.90-2.80[b]

[a]Assumes annual capital charges of 0.15 times capital investment allocated to fuel efficiency, no discount of future savings, and car driven 100,000 miles during its lifetime.
[b]Within the uncertainties the costs are the same for each mix shift.

SOURCE: Office of Technology Assessment.

Individual car prices will not necessarily change in proportion to their costs, in any case. Specifically, there are three reasons why it is difficult for U.S. manufacturers to finance automotive changes through price increases: competition from lower cost imports, the relationship between new and used car prices, and limited consumer willingness to tradeoff high car prices against lower gasoline bills. First, because high fuel-economy imports from Japan cost about $1,000 (1980 dollars) less than American-made cars,[33] U.S manufacturers have little freedom to raise prices without losing sales volume to imports (all things equal). International cost differences may narrow in the future, however, as foreign labor costs rise and if U.S. productivity increases.

Second, the effective price of new cars for most buyers includes a trade-in credit on an older car. Decline in demand for used cars, which might occur if older cars were significantly less fuel efficient than new ones and if maximum fuel economy were in demand, would effectively raise the price of new cars. This phenomenon would hinder a rapid mix shift.

Third, consumers may resist high prices for fuel-efficient cars because they tend to discount such future events as energy cost savings rather heavily, by perhaps 25 percent or more,[34] Discounting at high rates would cause consumers to demand relatively large amounts of fuel savings in return for a given increase in price. Each gallon saved seems to cost more if consumers discount at high rates, because discounting reduces the perceived number of gallons saved over the life of the car.

This phenomenon can be illustrated as follows: The undiscounted lifetime fuel savings from raising a car's fuel economy from 45 to 60 mpg is 557 gal; at a 25 percent discount rate the discounted savings is 227 gal (using a declining schedule of yearly fuel consumption) or about 40 percent of the actual savings. If it costs $150 to $350 per car to raise the fuel economy from 45 to 60 mpg, the cost per gallon saved would be $0.27 to $0.63 without discounting but about 2.5 times as much, $0.66 to $1.54, if fuel savings are discounted at 25 percent. Consumer behavior may be at odds with the national interest, because future savings of oil have a relatively low "social" discount rate for the Nation.

Maintenance

Automotive maintenance and service costs may increase with vehicle design change but the amount of increase depends on institutional as well as technological change. Manufacturers are modifying car designs to make servicing less frequent and less expensive, but—with more complex and expensive components in cars—there is a definite potential for increased repair costs. Also, use of new equipment, including electronic diagnostic units, may lead to higher real costs for service. For smaller shops, in particular, lack of familiarity with new technologies and problems with multiple parts inventories (necessary for servicing new- and old-technology cars) could add to consumer service costs. Because dealerships and larger service firms are in a better position to adjust to changing technology, they are likely to gain larger shares of the service market.

Available estimates of service cost changes for future cars are very speculative. For instance, CBO has estimated that maintenance and service costs associated with transmission improvements, adding turbochargers, and altering lubricants could raise discounted lifetime maintenance costs of new cars by $40 to $90 on average (assuming a 10 percent discount rate). The actual changes in maintenance costs, however, will depend heavily on the success of development work aimed at maintaining automobile durability with changing technology.

Electric and Hybrid Vehicles

Costs of producing electric (EV) and hybrid vehicles (EHV) will differ from those of producing conventional vehicles. EVs substitute batteries, motors, and controllers for fuel-burning engines and fuel tanks. Hybrid vehicles include most or

[33] U.S. Industrial Competitiveness: A Comparison of Steel, Electronics, and Automobiles, op. cit.

34 Evidence of high consumer discount rates for energy- efficient durable goods is presented in an article by J. A. Hausman, "Individual Discount Rates and the Purchase and Utilization of Energy-Using Durables," Bell Journal of Economics, vol. 10, No. 1 (spring 1979), and in a "Comment" article by Dermot Gately in the same journal, vol. II, No. 1 (Spring 1980).

all of the components of conventional vehicles as well as EVs, but in modified forms. The components required for electric propulsion, which contribute directly to vehicle cost, further add indirectly to cost because they change the structural requirements of the vehicle. The size and weight of batteries, in particular, increase the need for space and structural strength,[35] necessitating changes in vehicle design and weight increases.

Batteries are a major source of both direct and indirect cost. They may comprise 25 percent of total cost, depending on type, size, and capacity. * Batteries available for electric vehicles by 1990 may be priced (1980 dollars) at $1,700 to $2,700 (corresponding to production cost of $1,300 to $2,100) while advanced batteries available by 2000 may be priced below $2,000 (with production cost around $1,500).36

Electric motors are smaller, lighter, and simpler than internal combustion engines. Motor controllers, however, are relatively bulky and may be more expensive than the motors themselves, depending on their design. Motor-controller combinations likely to be available by 1990 may cost around $1,000. *

Estimates given in the report cited in footnote 36 suggest that near-term EVs and EHVs would cost at least sO percent more than comparable conventional vehicles. Technological advances in battery development could reduce electric and hybrid vehicle costs, however. Note that manufacturers may initially set the prices of EVs close to those of conventional cars to enhance their appeal to consumers.

Methanol Engines

Production of automobiles designed to run on methanol entails only minor modifications of the engine and fuel system. Consequently, the cost increase for engines designed to use methanol are minor. However, the cost of modifying an engine to operate efficiently on a fuel for which it was not designed can be more significant. One estimate is that retrofitting a gasoline-fueled vehicle for methanol use would cost $600 to $900, and redesigning an engine for methanol combustion would cost $50 to $100 per vehicle.[37] Ford, which is converting several Escorts to methanol combustion for the Los Angeles County Energy Commission, estimates that necessary modifications cost about $2,000 per vehicle, although they would cost less if larger numbers of cars were converted.[38]

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[35]CBO, op. cit.

*Batteries may comprise about 25 to 30 percent of the weight of an electric vehicle and about 20 to 25 percent of the weight of a hybrid vehicle. The electric motor and controller may comprise about 10 percent of an electric or hybrid vehicle's weight.

[36]W.M.Carriere,W. F. Hamilton, and L. M. Morecraft, General Research Corp., Santa Barbara, Calif., "The Future Potential of Electric and Hybrid Vehicles," contractor report to OTA, August 1980.

*Battery size is a function of the number and size of constituent cells. Battery capacity—and therefore vehicle driving range—is a function of the amount of energy deliverable by each pound of battery.

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[37]William Agnew, G.M. Research Laboratories, private communication.

[38]"Ford Converts 1.6L Escorts for Methanol," Ward's Engine Update, Feb. 15, 1981.

APPENDIX A.–PROSPECTIVE AUTOMOBILE FUEL EFFICIENCIES

Table 5A-1 summarizes the prospective automobile fuel-efficiency increases used in OTA's analysis. The technologies involved are described in more detail below. In addition, alternative heat engines are discussed and the reasons for not including them in the projections to 2000 are explained.

More or Less Conventional Engines

There is more diversity among the engine technologies listed in table 5A-1 than in any other category.

The table indicates increases in fuel economy of 15 percent at most for vehicles using improved S1 engines compared with the baseline 1985 car—everything else remaining the same. Sources of such improvements include:

- smaller engines, because lighter cars will not require as much power and because the engines themselves will also continue to decrease in weight;
- decreases in engine friction–e. g., from new piston ring designs, smaller journal bearing diame-

Table 5A-1.– Prospective Automobile Fuel= Efficiency Increases, 1986.2000

Technology	Percentage gain in fuel efficiency					
	High estimate			Low estimate		
	1986-90	1991-95	1996-20000	1986-90	1991-95	1996-2000
Engines						
Spark-ignition (S1)	10	10-15	15	5	5-1o	5-1o
Diesel:						
Prechamber.	15	15		15	15	
Open chamber	25	35	35	20	20	25
Open chamber (S1) stratified charge (SC)		15	20			
Hybrid diesel/SC			35			
Transmissions						
Automatic with lockup torque converter	5	5	5	5	5	5
Continuously variable (CVT).		10	15			10
Engine on-off		10	10			10
Vehicle system						
Weight reduction (downsizing and materials substitution)	8	13	18	4	8	10
Resistance and friction (excluding engine)						
Aerodynamics.	2	3	4	1	2	3
Rolling resistance and lubricants		2	3	1	1	2
Accessories	2	3	4	1	1	2

a Improvements i. fuel efficiency are expressed as percentage gain in mpg compared with an anticipated average 1985 passenger car. The 1985 average car used as a reference has an inertia weight of about 2,500 lb, is equipped with spark-ignition engine, three-speed automatic transmission, and radial tires, and has an EPA mileage rating (55 percent city, 45 percent highway) of 30 mpg. The fuel efficiencies of the individual baseline cars, which are used to calculate future fuel efficiencies in each size class, are given in tables 23 and 24. Percentages are given on an equivalent Btu basis where appropriate—e.g., for diesels, which use fuel having higher energy content per gallon than gasoline, the percentage gain refers to miles per gallon of gasoline equivalent, which is 10 percent less than miles per gallon of diesel fuel. The table does not include efficiency improvements from alternate fuels such as alcohol.

SOURCE: Office of Technology Assessment

ters, increases in stroke-to-bore ratios, improved engine oils;

- new combustion chamber designs, particularly fast-burn chamber geometries that permit lean operation at higher compression ratios;
- further refinements to electronic engine control systems (although most of the possible gains will have been achieved by 1985); and
- decreases in heat losses, consistent with allowable thermal loadings of internal engine parts and the octane ratings of available fuels.

Friction, which goes up with displacement, is a major source of losses in piston engines. Smaller engines cut friction losses, and also operate with less throttling—another source of losses—under normal driving conditions. Turbocharging is one way to make the engine smaller, improving fuel economy without sacrificing performance-albeit at rather high cost. Adding a turbocharger can help a small engine meet transient peak power demands and improve the driving-cycle fuel economy of both S1 and CI engines by perhaps 5 to 10 percent—provided economy and not performance is the goal. Further applications are possible if the benefits perceived by consumers outweigh the price increases.

Bigger gains over the 1985 baseline S1 powered car are possible with CI engines (table 5A-1). In the past, most efforts on diesels have been directed at heavy-duty applications such as trucks. Although the efficiency advantage of CI engines relative to S1 engines decreases as engines become smaller, considerable scope remains for improving the driving-cycle efficiency of passenger-car diesels. In particular, all diesel engines now used in passenger cars are based on a "prechamber" design (also termed indirect injection). The combustion chambers in such engines consist of two adjoining cavities, with fuel injected into the smaller prechamber. At present, prechamber engines have several advantages for passenger vehicles. They are quieter than open-chamber (or direct injection) diesels, have wider ranges of operating speeds, and lower-cost fuel injection systems; in addition, emissions control is easier and smoke limitations are not as serious. [39]

As development of open-chamber diesels for passenger cars continues, substantial fuel-economy improvements can be expected–perhaps 15 percent above the levels that might be achieved with prechamber diesels, themselves of course considerably better than S1 engines (table 5A-1)—assuming NO_x and particulate emissions can be controlled, and noise held to acceptable levels. The efficiency advantages of the open chamber engine stem largely from higher volumetric efficiency, lower heat losses, and more rapid

[39] "Future Passenger Car Diesels May Be Direct injection, " Automotive Engineering, June 1981, p. 51.

combustion. Estimates[40] indicate that a 1.2-liter open chamber diesel in an automobile with an inertia weight of 2,000 lb should be able to achieve a 55/45 EPA fuel-economy rating of 60 to 65 mpg (with a manual transmission). Such estimates assume emissions standards for CI engines that do not severely compromise efficiency. Standards for NO_x and for particulates—which, besides making diesel exhaust smoky, are health hazards—are the most difficult to meet. In general, measures that reduce NO_x increase particulate emissions, and vice versa. To some extent, diesel engines will probably face continuing sacrifices in fuel economy to meet emissions standards.

To emphasize efficiency gains rather than differences in the energy content of various fuels, the diesel engine improvements listed in table 5A-1 are all based on miles per gallon of gasoline equivalent. Because diesel fuel contains more energy (Btu) per gallon than gasoline, miles per gallon of diesel fuel would be 10 percent greater than miles per gallon of gasoline equivalent. For example, a 1990 prechamber diesel is expected to be about 10 percent more efficient than an S1 engine in the low estimate, but about 20 percent better in terms of miles traveled per gallon of fuel.

Stratified-charge (SC) engines (table 5A-1) are S1 engines that have some of the advantageous features of diesels–such as potentially higher efficiency and potentially easier control of emissions, although low emissions levels have been difficult to achieve in practice—as well as the disadvantages of diesels, such as higher production costs. [41] SC engines, like diesels, operate with a heterogeneous distribution of fuel and air in the combustion chamber. But unlike diesels, the SC engines now in production burn gasoline and use spark plugs. SC engines, again like diesels, come in two varieties–prechamber, such as the Honda CVCC engine that has been sold in the United States since 1975, and open-chamber (also called direct injection). Prechamber engines have shown little if any fuel economy advantage, while open chamber SC engines promise good efficiencies in theory but have not yet been successfully reduced to practice. As with open-chamber diesels, it has proven difficult to achieve good response and smooth operation over the relatively wide range of loads and speeds needed for passenger cars. Moreover, open-chamber SC engines have the most potential in larger engine sizes; for a smaller engine operating at a higher load level—a situation now more prevalent—one of the major advantages of the SC engine, its lower throttling requirement, is less of a factor. Such an engine would be more costly to produce than a conventional S1 engine, though less expensive than a diesel.

Another potential advantage of open-chamber SC engines is their tolerance for a wide range of fuels— including both gasoline and diesel, as well as alcohols and other energy carriers not necessarily based on petroleum. The broad fuel-tolerance of SC engines has led to a good deal of work directed at military applications. Further, the low-emissions potential of SC engines provided early stimulus for R&D directed at automotive applications. Open-chamber SC engines could find a place in passenger cars during the 1990's if the remaining problems are overcome.

Another possible path leads to a merging of diesel and SC engine technologies (table 5A-1). This might be visualized as a diesel with spark-assisted ignition. Spark-ignition would increase the tolerance of the engine to fuels with poor ignition quality (i.e., to fuels with a low cetane numbers such as gasoline or alcohols), but the combustion process would be more nearly a constant pressure event, as in a diesel.

Gas Turbine, Brayton, and Stirling Engines

Prospects for other "alternate engines" remain dim; in particular, most alternatives to S1 and CI engines are poorly suited to small cars. Candidates include gas turbines (i.e., those operating on a Brayton cycle), or the Stirling cycle powerplants that have also been widely discussed for automotive applications. At present, such alternatives to S1 and CI engines suffer many drawbacks. Gas turbines, for example, would need ceramic components to achieve high efficiencies at low cost–most critically in the power turbine, because high turbine inlet temperatures are needed to raise the efficiency. Ceramics are inherently brittle, and a great deal of work remains to be done before durable and reliable engine parts can be mass-produced from materials such as silicon nitride. The technical problems are more severe for highly stressed moving parts such as turbine rotors than for the applications such as combustor heads envisioned for Stirling engines. While the problems of developing tough ceramics for high-temperature applications in energy conversion devices are receiving considerable R&D support, success cannot be guaranteed. Even if the ceramics can be developed successfully this will not necessarily suffice to make gas turbines (or Stirling-cycle powerplants) practical for use in passenger cars.

With or without ceramic components, automotive gas turbines would, at least initially, be high in cost; and beyond high costs, they suffer a number of other disadvantages as automobile engines. Although gas

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[40] Ibid.
[41] J. A. Alic, op. cit.

turbines are highly developed powerplants in the large sizes used for stationary power or for marine and aircraft applications (500 hp and above) and ceramic components would allow higher operating temperatures and theoretically high efficiencies, turbine engines do not scale down in size as well as reciprocating engines. Both compressors and power turbines lose efficiency rapidly as their diameters decrease toward the sizes needed for smaller cars (75 hp and below). Brayton-cycle powerplants also have generally poor part-load fuel economy–which is a severe disadvantage in an automobile, where low-load operation is the rule. Furthermore, they need complex transmissions because the power turbine runs at speeds much higher than those of reciprocating engines. Fixed-shaft turbines, in particular, pose difficult problems in matching engine operating characteristics to automobile driving demands. But the most critical drawback of gas turbine powerplants is finally that they are unlikely to achieve competitive efficiencies when sized for small cars—those in the vicinity of 2,000 lb. As these size classes become a larger fraction of the market, the prospects for automotive gas turbines grow dimmer.

Stirling-cycle engines are at much earlier stages of development. High efficiency in small sizes is a more realistic possibility for a Stirling engine than for a gas turbine, but the costs of Stirling engines are likely to be even higher than those for gas turbines [42]–and both engines will probably always be more expensive to manufacture than S1 engines. Like turbines, ceramic components will be needed to achieve the best possible efficiencies in Stirling-cycle powerplants–here the most immediate needs are probably in the heater head and preheater. Seals have also been a persistent block to practical Stirling-cycle powerplants.

Both gas turbine and Stirling engines–because combustion is continuous–have intrinsic advantages in emissions control, and can burn a wide range of fuels. But intermittent-combustion engines (e.g., S1 and Cl) have thus far demonstrated levels of emissions control adequate to meet regulations. Broad fuel tolerance is again not unique to gas turbine and Stirling engines. These advantages are probably not enough to overcome the drawbacks of such engines, at least over the next 20 years.

Transmissions

Table 5A-1 lists a pair of developmental paths for automatic transmissions. (Manual transmissions are not explicitly included in the table; although more

American purchasers are now choosing manual transmissions as small cars take a greater share of the market, automatics still predominate.) Geared automatic transmissions with lockup torque converters are already available in some cars; these are straightforward extensions of current technology, in contrast to continuously variable transmissions (CVTs). In principle, an engine on-off feature—in which the powerplant can be automatically shut off when not needed–could be implemented with either system (or with manual transmissions). Placing the engine drive shaft parallel to wheel axles would also yield a small improvement in fuel economy–because crossed axis gears could be replaced by more efficient parallel axis gears, or chains.

Geared automatic transmissions with either three or four speeds and a lockup torque converter-or with a split power path, an alternate method for m minimizing converter slip and the consequent losses—are already on the market. A fourth gear ratio gives a better match between engine operating characteristics and road load demands. The fourth speed, for example, may function as an "overdrive" to keep engine load and efficiency high at highway driving speeds. Neither development—bypassing the torque converter when possible, or adding a fourth speed to an automatic transmission—is new, but the added costs of such designs are now more likely to be judged worthwhile. Many manual transmissions incorporate five rather than four speeds for similar reasons—the added gear benefiting fuel economy, as well as performance at low power-to-weight ratios.

Although the efficiencies of manual transmissions are greater than for automatics—that is, less of the power passing through the transmission is dissipated–the fuel economy achieved by many drivers may be as high or higher in cars equipped with an automatic transmission. By relying on the logic designed into the transmission to chose the appropriate gear ratio for given conditions, wasteful driving habits–e.g., using high engine speeds in intermediate gears–can often be avoided.

Further improvements in the control systems for automatic transmissions, as well as other changes such as variable displacement hydraulic pumps, will help to counterbalance their inherently lower efficiencies. In the past, automatic transmissions have depended on hydromechanical control systems—just as engines have. Hydromechanical control–although well developed and effective— limits the number of parameters that can be sensed, as well as the logic that can be employed. In the past, automatic transmissions have generally decided when to shift by measuring engine speed, road speed, and throttle position. By moving to fully electronic control systems, a greater number

[42] "Alternate Powerplants Revisited, " Automotive Engineering, February 1980, p. 55.

of engine parameters can be measured, and more sophisticated control algorithms implemented—enabling the transmission to be "smarter" in selecting among the available speeds. Electronics might also be used with manual or semiautomatic transmissions to help the driver be "smarter."

As pointed out above, increasing the number of speeds in an automatic or manual transmission—from three to four or five–can help fuel economy. Although trucks often have many more speeds (for reasons beyond fuel economy), mechanical complexity (in automatics) and the demands on the driver (for manual transmissions)—as well as rapidly diminishing returns when still more speeds are added—will probably continue to limit the number of discrete gear ratios in passenger-car transmissions to four or five. if, however, discrete gearing steps can be replaced by a stepless CVT, then the engine could operate at the speed and throttle opening (or fuel flow for a diesel) that would maximize its efficiency for any road-load demand—i.e., engine speed would be largely independent of vehicle speed. [43] If otherwise practical, such a transmission could give markedly better fuel economy than other automatic transmissions–provided the CVT itself was reasonably efficient. Smooth, shiftless operation is another potential advantage of CVTs.

Continuously variable speed ratios can be accomplished in a variety of ways—e.g., the hydrostatic transmissions sometimes used in farm and construction equipment. A series hybrid electric vehicle—in which the engine drives a generator, with the wheels powered by an electric motor, typically drawing from batteries as well as the generator–in effect uses the motor-generator set as a CVT. Hydrostatic or electric CVTs are expensive and inefficient. CVTs used in past applications to passenger cars have generally been all-mechanical—e.g., based on friction drives, or belts. Typically, such designs have been limited in power capacity and life by wear and other durability/reliability problems.

At present, the most promising CVT designs are those based on chains or belts. Continuing development may well overcome or reduce the significance of their drawbacks relative to the fuel savings possible. These fuel economy improvements could be of the order of 10 percent compared with a conventional automatic transmission—again, depending on the efficiency of the CVT. Fuel economy better than that of a properly driven car with a manual transmission would be more difficult to achieve. Although the CVT

would permit the engine to operate more efficiently, poorer transmission efficiency would counterbalance at least some of the savings. One reason that CVTs are expected to have lower efficiencies is the need for a startup device, such as a torque converter, in addition to the CVT mechanism itself. Given that the production costs of a CVT would also be higher than those of a manual design—in part because of the start-up device—CVTs appear most likely to find a place as replacements for conventional automatic transmissions.

The third transmission technology listed in table 5A-1, engine on-off, has been placed in this section only for convenience—it could just as well appear in the engine category. "Engine on-off" systems, by which the powerplant can be automatically shut off during coasting or when stopped at signal lights or in traffic, are in principle easy to implement. Indeed, when current engines are equipped with electronic fuel injection the fuel flow is sometimes cut off when coasting above a predetermined speed. For an engine on-off design to be practical (and safe), the engine must restart quickly and reliably, and the operation of the system should not otherwise affect driveability—i.e., it should be operator-invisible, primarily a matter of control system design. Engine on-off systems are under development, and presumably will be implemented if the production costs prove reasonable compared with the expected fuel savings.

Vehicle Weight

The final group of technologies in table 5A-1–vehicle systems—includes several means of reducing power demand, hence the fuel consumed in moving the car. As discussed in the body of this chapter, the single most important means of reducing fuel consumption is by reducing the weight of the vehicle; a 1 -percent decrease in weight typically cuts fuel consumption by 0.7 to 0.8 percent, provided engine size is reduced proportionately. Fuel consumption can also be lessened by reducing air drag, frictional, and parasitic losses–such as accessory demands.

The easiest way to decrease the weight of an automobile is to make it smaller. In most newly designed cars, front-wheel drive is adopted to preserve interior volume, while considerable attention has been given to maximizing space utilization and removing unneeded weight. For cars of a given size, materials with higher strength-to-weight ratios can be used where cost effective, provided they meet requirements for corrosion resistance and stiffness. Progress has also been made by specifying less conservative margins of safety for structural design. Many of the steps taken to reduce vehicle weight interact—i.e., taking weight

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[43] B.C.Christenson, A. A. Frank, and N. H. Beachley, "The Fuel-Saving Potential of Cars With Continuously Variable Transmissions and an Optimal Control Algorithm, " American Society of Mechanical Engineers Paper 75-WA/Aut-20, 1975.

out of one part of the car, perhaps by replacing 5-mph bumpers with 2-mph bumpers, allows secondary weight savings elsewhere in the body and chassis.

In the future, big gains will be harder to achieve. Most of the waste space has already been taken out of newly designed American cars. Overhangs for styling purposes are being reduced or eliminated, door thicknesses decreased, space utilization in passenger compartments and trunks more carefully planned. Considerable progress can still be made through careful detail design, but the easiest steps are being taken. In the future, tradeoffs between space for passengers and luggage and the weight of the vehicle will be more difficult to manage.

The two basic approaches to reducing weight are: 1) to use materials which provide comparable performance characteristics but weigh less; and 2) to design each component and subsystem with minimum weight as a primary objective—the latter more important now than in the past, when the costs associated with extra testing and analysis were harder to justify through savings in materials and fuel. The first path also tends to raise the manufacturer's costs because substitute materials usually cost more.

Material characteristics most critical in automobile structures are cost, strength, stiffness, and corrosion resistance. Costs—of the material itself, and of the fabrication processes that the choice of material entails— are in the end the controlling factors, as for most mass produced products. Nonstructural parts carry different demands but often less opportunity for saving weight (e.g., upholstery and trim, typically already plastics).

Iron and steel have been the materials of choice for building cars and trucks–as for other mechanical systems—because of their combination of good mechanical properties and low cost. Iron castings have been widely used in engines and powertrain components, steel stampings and forgings in chassis members, bodies, and frames (now often unitized). Highly loaded parts are generally made from heat treated alloy steels–e.g., some internal engine components, as well as gears, bearings, shafts. But elsewhere mild steel has been chosen because it is cheap and easy to fabricate; it can be easily formed and spot welded, gives a good surface finish, and takes paint well. Greater quantities of high-strength, low-alloy steels are now being specified–particularly for bumpers and more critical structural applications such as door guard beams; some new cars contain 200 lb of high-strength steel, triple the amounts of a decade ago. [44] Thinner body parts with good corrosion resistance can be made from galvanized or aluminized sheet steel.

The strength-to-weight ratio of inexpensive, low-strength steels can also be equaled or exceeded by alloys of aluminum and magnesium, as well as by non-metallic materials such as reinforced plastics. Aluminum usage, now 115 to 120 lb per car, is expected to reach 200 lb per car by 1990—mostly in the form of castings [45] Aluminum can substitute for iron and steel in engines and transmissions—cylinder heads as well as simpler, less critical components such as housings, covers, and brackets. Magnesium and reinforced plastics are other candidates for some of these applications (use of magnesium is currently limited by high costs, but these may come down in the future). However, aluminum sheet for body parts and structural members has been limited not only by high costs but by difficulty in spot welding–a problem that new alloy compositions are helping overcome.

A variety of plastics and fiber-reinforced composites –ABS, glass-reinforced polyester sheet molding compound, reaction-injection molded polymers with or without reinforcement—are being specified for production parts; some have been used for years. While more of these materials will be used in the future, GM's Corvette–a high-priced specialty vehicle made in quantities small compared with most other domestic vehicles—remains the only mass-produced American car with a glass-reinforced plastic body. Introduced nearly 30 years ago but never emulated, this illustrates the continuing advantages of metals, particularly at high production levels.

In the past, plastics have generally been applied to nonstructural parts. Polymer-matrix composites are now candidates for some structural applications—one 1981 car had a fiberglass rear spring weighing 8 lb, compared with 41 lb for the steel spring it replaced. [46] Examples of related applications, none yet in production, are driveshafts and wheels. Other types of composites—i,e., laminates consisting of two metal layers, probably steel, sandwiching a plastic such as polypropylene–may have potential as body materials. The thickness of the laminate makes it more rigid in bending for a given weight, and the plastic dampens noise and vibration; such laminates, like many other composite materials, are now too costly for widespread use. [47]

[44]H. E. Chandler, ''Useage Update: Light, Longer Lasting Sheet Steels for Autos, " *Metal* Progress, October 1981, p. 24.

[45]HEChandler,''ALook Ahead at Auto Materials and f%ocesses in the 80's," *Metal* Progress, May 1980, p. 24.

[46]Ibid,

[47]H. S. Hsia, "Weight Reduction for Light Duty Vehicles, 1980 Summary Source Document" (draft), Department of Transportation, Transportation Systems Center, March 1981, p. 8-31.

Improvements in steels and their applications still offer the greatest scope for near-term weight savings in passenger cars—one reason is that the designer's job becomes more difficult when materials are changed. But the manufacturing problems mentioned above for aluminum as a body material—difficulty in spot welding, forming characteristics that call for changes in die design—at least remain within the realm of conventional, mass production metalworking techniques. Plastics and composites demand processing quite different from that used for metals—and high volume production of structural parts made from such materials is new, not only for the automakers, but for virtually all industries. Furthermore, unconventional materials may need additional engineering analysis and testing–e.g., they are often susceptible to different failure modes (such as environment-induced embrittlement, or discoloring). In fact, the second avenue for weight reduction is precisely an improvement in design methods.

With better methods for analyzing and controlling the stress and deflection in the vehicle structure, weight can be reduced without sacrificing structural integrity. Through better understanding of the failure modes of the materials used, as well as service loadings, margins of safety can be reduced. Both analysis and testing are important to these objectives. The greatest strides have come from widespread adoption by the automobile industry of finite-element methods for structural analysis, Not only can body and chassis structures be designed with more precise control over stresses and deflections—eliminating unnecessary material—but finite-element techniques can also help reduce the weights of engines and other powertrain components; section sizes of engine blocks can be decreased, for example.

The weight reductions, hence fuel economy gains, that are possible through materials substitution are limited primarily by costs–both material cost and manufacturing cost. Graphite reinforcements for polymers perform better than glass, for example, but are considerably more expensive; at the highest strength levels, aluminum alloys, in addition to being expensive and difficult to form, cannot be welded. If the costs justify the benefits in terms of fuel economy and other performance advantages—e.g., corrosion resistance—then automobile designers will choose new materials. In some cases, costs will come down as production volume increases, but there will always be a point of diminishing returns. Nonetheless, continued attention to detail design with conventional materials —with which the automakers have engineering and production experience–and improved methods of structural analysis, can give substantial reductions in

weight, as table 5A-1 indicates. Even though downsizing and weight reduction will have proceeded considerably by 1985, improvements will continue—often rather gradually, as manufacturers gain confidence in, and experience with, new materials and improved design methods.

Safety poses a further constraint on the selection of structural materials for automobiles. The tradeoffs between vehicle size and occupant safety are discussed in chapters 5 and 10. For a vehicle of a given size, the mechanical properties of the structural materials are one of the factors on which passenger protection depends. Because the structure needs to be able to absorb large amounts of energy in a collision, the materials should be capable of extensive plastic deformation, or else able to absorb energy by some alternative process such as microfracturing while being crushed. This may limit applications of higher strength materials—both metals and nonmetals—because capacity for plastic deformation is inversely proportional to strength; it may also pose difficult design problems for some composite materials.

Aerodynamic Drag

A lighter automobile needs less power for acceleration and for constant speed travel and therefore consumes less fuel. A car with less aerodynamic drag burns less fuel at any given speed, but the power needed for acceleration is not directly affected. Because drag caused by air resistance is proportional to frontal area and to speed squared, drag reduction helps most at higher speeds–i.e., during highway driving.

Smaller cars have less frontal area, hence less drag. But drag can also be reduced by making a car more "streamlined. " This characteristic is quantified by the drag coefficient-which has a value of 1.2 for a flat plate pushed through the air, but only 0.1 for a teardrop shape. For complex geometries such as airplanes or automobiles, drag coefficients can be precisely determined only by experiment. Extensive–and expensive—wind tunnel testing is the basic technique for minimizing the drag coefficient of an automobile.

Theoretical aspects of the aerodynamics of ground vehicles are poorly understood, particularly for shapes as complex as automobile bodies. Interactions between the stationary roadway and the moving car are a particular problem. Drag reductions are sensitive not only to overall vehicle shape—e.g., the sloped front-ends now common on passenger cars—but to relatively subtle details–such as integration of the bumpers into the front-end design, and the flow of air through

the radiator. Testing and experiment are required before the final form can be chosen.

While typical cars of the early 1970's had drag coefficients in the range of 0.50 to 0.60, many current models have values closer to 0.45, or less; the 1982 Pontiac 6000 has a claimed drag coefficient of 0.37. [48] Reductions to values of less than 0.35 are possible, but eventually limited by practical compromises involving the utility of the vehicle (passenger and luggage space can suffer, as well as accessibility for repairs), safety (a streamlined design may compromise visibility for the driver), and manufacturing costs (curved side glass can cut drag but is more expensive).' Even so, by 1990 drag coefficients may average 0.35 or less. [49]

Nonetheless, as table 5A-1 indicates, improvements in fuel economy in the years past 1985 from continuing reductions in aerodynamic drag will be relatively small. The reasons are, first, that considerable progress has already been made, and more can be expected between now and 1985–and the returns from drag reduction rapidly diminish (frontal areas are constrained by the need to fit people into the car; no practical vehicle could approach the lower limit drag coefficient of the teardrop shape) —and, second, that drag reduction has the greatest benefits at high speeds, whereas most driving is done at lower speeds. In general, a 10-percent reduction in drag will yield an improvement in driving-cycle fuel economy of perhaps 2 percent. [50]

Rolling Resistance

Even in the absence of air resistance, some fuel would be burned in pushing a car at a constant speed. This rolling resistance depends on tire characteristics,

and on friction and drag in moving parts such as axle bearings. It also depends on the road surface (concrete offers slightly less rolling resistance than asphalt). Most of the resistance is caused by deformation in the tires. Carcass design, tread pattern, and inflation pressure all affect resistance. Radial tires decrease resistance compared with bias-ply carcasses, with fuel-economy improvements of 2 to 5 percent possible; [51] more aggressive tread patterns—e.g., snow tires—increase resistance; higher inflation pressures decrease resistance.

Improved lubricants and bearing designs can also cut resistance slightly, as can brakes with minimal drag. However, more scope for fuel-economy improvements through better lubricants exists elsewhere in the vehicle—particularly in engines, but also in transmissions and rear axles—where more "slippery" oils, as well as design changes that minimize churning and oil spray, can reduce viscous drag. Although decreases in friction and rolling resistance benefit fuel economy at low speeds almost as much as at high, many of the possible gains have already been achieved, or are in sight—thus, further improvements after 1985 will be small (table 5A-1).

Accessories

Some of the power produced by the engine is used, not to move the car or to overcome the engine's internal friction, but in driving pumps, fans, and accessories. To produce this power, fuel must be burned. Among the specific parasitic losses that automobile designers strive to minimize are those associated with cooling fans, air-conditioning compressors, power-steering pumps, and electrical loads supplied by the alternator. Decreases are possible in many of these, as table 5A-1 indicates, though often at somewhat greater cost. In some cases, downsizing the vehicle helps to reduce or eliminate parasitic losses–e.g., power steering may not be needed.

[48]J. Burton, "82 Pontiac 6000: A Step Further, " Autoweek, Nov. 30, 1981, p. 10.

[49]D.Scott,''DoubleLoopCuts Wind Tunnel Size and Cost, " Automotive Engineering, May 1981, p. 69.

[50]Automotive Fuel Economy Program: Fifth Annual Report to the Congress (Washington, D. C.: Department of Transportation, January 1981), p. 119.

[51] Ibid.

APPENDIX B.–OIL DISPLACEMENT POTENTIAL OF ELECTRIC VEHICLES

Electric Vehicles and Electric Utilities

The extent to which electric vehicle (EV) technology can contribute to the national goal of reducing oil imports will depend on the availability and use of non-

petroleum-based electricity for vehicle recharging and the fuel consumption of the car the EV replaces. Because of the limited performance of EVs, they would most likely be substitutes for relatively fuel-efficient small cars. Also, because of the limited range and

hauling capacity of EVs, it is assumed that they can replace only 80 percent of the (10,000 miles per year) normal travel in a gasoline car. The remaining 2,000 miles per year would have to be accomplished with a possibly rented gasoline-fueled car, which might be less fuel efficient than the small car that the EV replaced. This latter complication was ignored, however, so the results shown here are slightly more favorable in terms of net oil displacement than might be the case in practice.

Figure 59-1 shows the consequences of introducing EVs in terms of either increased petroleum use, or net petroleum savings, for alternative assumptions about automotive fuel economy. For example, referring to the figure, if the fuel economy of the car replaced by an EV is 60 mpg (case A), then one could save as much as 133 gal per year or increase petroleum consumption by 123 gal (of gasoline equivalent) per year depending on whether, respectively, all or none of the recharge electricity is petroleum-based. * As long as the fraction of petroleum used for generating recharge energy for EVs in this case is less than about 50 percent, the introduction of EVs will result in net petroleum savings. In case B, where a car that achieves 40 mpg is replaced by an EV, the fraction of petroleum used for generating recharge energy must be less than about 80 percent to result in net petroleum savings.

Utilities plan their capacity and operations to ensure that the maximum instantaneous demand on the system, typically occurring at midday, can be met. This

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*Assumes that electric vehicle recharge energy is 0.4 kWh/mile.

implies that peakloads are satisfied with generating capacity that is idle at other times. A utility will thus respond to demand fluctuations by using the most efficient ("baseload" as well as "intermediate") plants as much as possible and progressively adding other "peaking" plants as loads increase. Baseload plants, which often cannot be adjusted rapidly (i.e., under 2 hours) to respond to demand fluctuations, are either nuclear, hydro, geothermal, or steam (oil, coal, or gas). Peaking plants can be operated for short-term response and are gas turbines fueled by oil or natural gas and pumped-storage hydro. The ability of utilities to handle the additional load created by EVs will depend on such factors as total generation potential, the equipment and fuel mix, and the time pattern of demands. These characteristics generally vary by region (fig. 59-2) as illustrated in table 59-1,

Figure 59-3 shows a peak summer demand curve and equipment mix for an individual, representative utility. Also shown are the likely changes in the load profile that would occur with the addition of EV loads under the following conditions: 1) recharging occurs over 12 hours during the night when demands on the system are the smallest, 2) recharging occurs uniformly during the day, and 3) recharging occurs during 2 hours at midday. As long as the additional EV load occurs either at night or evenly throughout the day, this load could be accommodated by increasing baseload output. Recharging over 2 hours during the day would be satisfied with peaking plants.

Assuming that the available oil-fueled baseload capacity used for recharging EVs is proportional to the amount of oil-fueled baseload in the system, figure
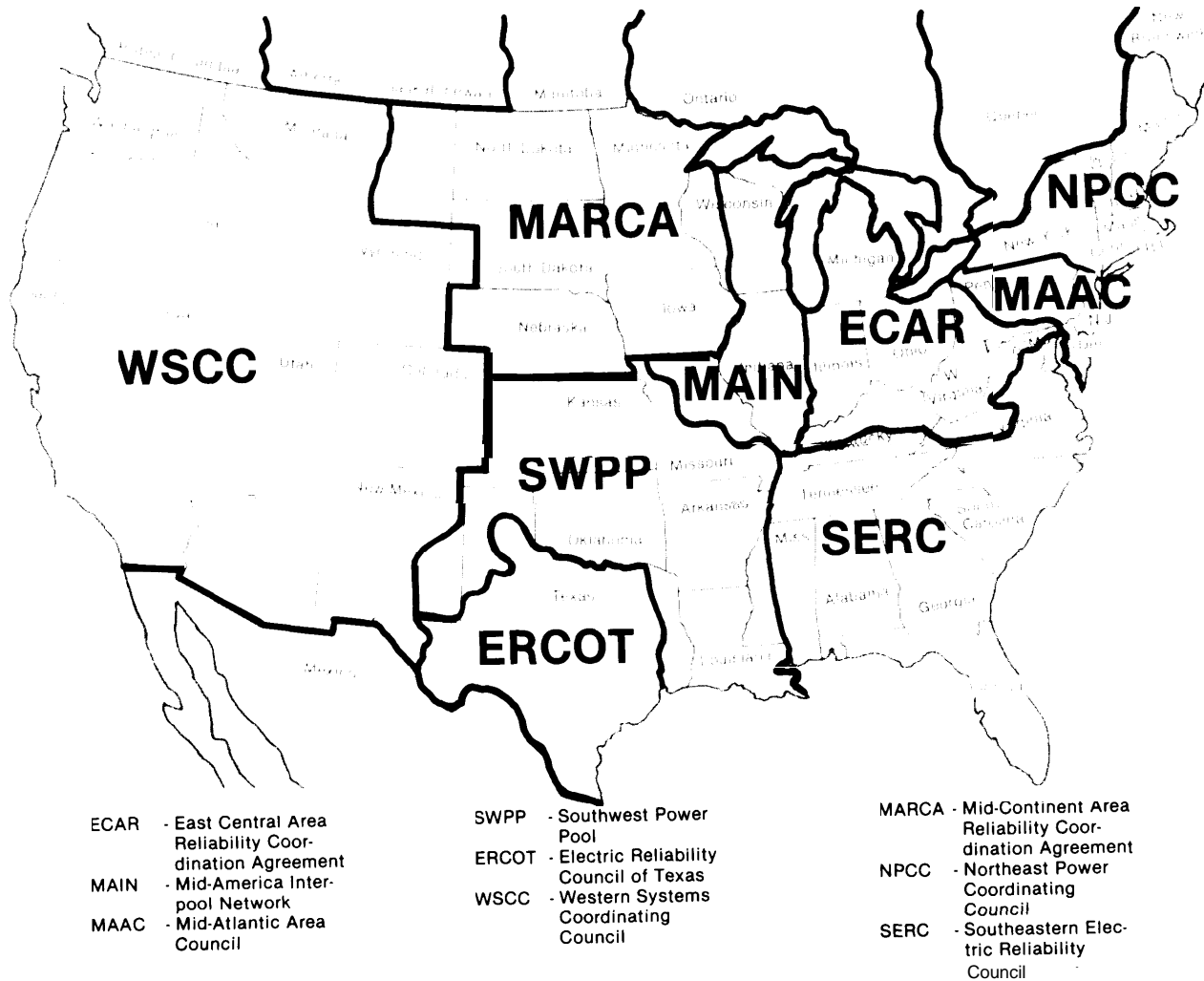
Figure 5B-1.- 'Relationship Between the Net Fuel Savings From the Use o f EVs and the Fuel Used for Electric Generation
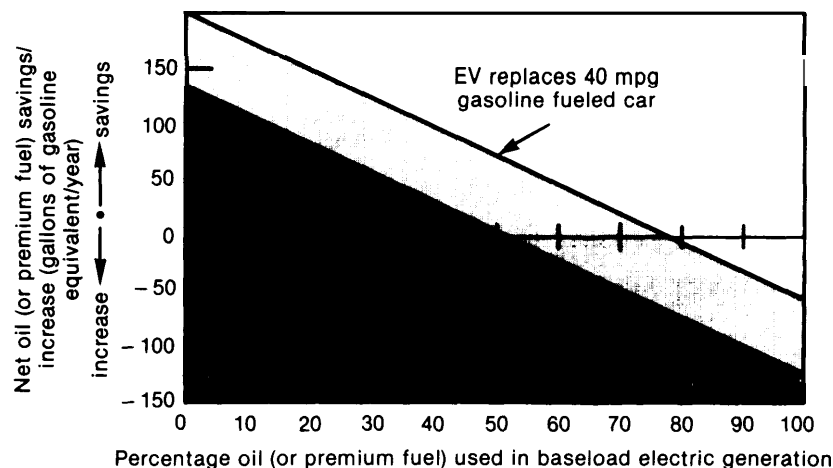
SOURCE: Office of Technology Assessment.

Figure 5B-2.— Regional Electric Reliability Council Areas

ECAR	- East Central Area Reliability Coor- dination Agreement	SWPP	- Southwest Power Pool	MARCA	- Mid-Continent Area Reliability Coor- dination Agreement
MAIN	- Mid-America Inter- pool Network	ERCOT	- Electric Reliability Council of Texas	NPCC	- Northeast Power Coordinating Council
MAAC	- Mid-Atlantic Area Council	WSCC	- Western Systems Coordinating Council	SERC	- Southeastern Elec- tric Reliability Council

SOURCE: Department of Energy, Energy Information Administration, April 1978

5B-4 can be used to determine the fuel efficiency that would be required of a small automobile if the overall oil consumption of the small automobile is to be equivalent to an EV in each region. For example, at one extreme, the Texas region uses not oil in its base-load, so an EV always consumes less oil, and at the other extreme, in the northeast a gasoline-fueled car would have to get about 50 mpg if it were to consume an equivalent amount of oil as an EV. In terms of pre-mium fuel, * the extreme points are several hundred mpg in the midcontinent area and about 40 mpg in

the Texas region to achieve a fuel-use equivalence be-tween a small car and an EV.

The electricity requirements and oil/premium fuel savings for an EV fleet which constitutes 20 percent* of the total vehicle fleet are shown in table 5B-2. As can be seen, as long as the EV fleet can be recharged using baseload capacity, regions should be able to meet the additional load with existing available base-load capacity. In general, the Northeast, West, and Southeast regions would utilize the greatest   absolute amounts of oil-fueled baseload capacity if EVs were

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*Oil + natural gas = premium fuel.

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*A 20-percent market penetration is considered to be the upper bound on EV use through 2010,

Table 5B-1.—Utility Capabilities by Region (contiguous United States) [a]

Region [b]	Installed capacity (x1O³MW)	Net capability (x 1 O³MW) [c]	Available baseload capacity (x10³MW) [d]	Available peaking capacity (x 1O³MW) [e]	Percent of baseload that is fueled by: Oil	Percent of baseload that is fueled by: Gas
ECAR	84.9	79.1	19.6	1.3	6.7	0.2
MAAC	44.0	40.6	7.1	2.2	35.3	0.0
MAIN	43.1	39.9	7.6	0.6	12.7	1.1
MARCA	25.4	24.4	5.1	0.8	2.5	0.9
NPCC	50.9	49.8	11.4	2.3	60.4	0.0
SERC	113.7	103.1	17.5	2.6	17.9	0.2
SWPP	48.9	46.1	6.8	0.4	21.6	42.8
ERCOT	40.9	39.9	9.7	0,0	0.0	75.7
WSCC	94.6	93.3	22.0	1.4	26.9	2.3
Total	546.4	516.2	106.8	11.6	20,9	10.8

aUnless otherwise indicated data are taken from the *1980* Summary, National Electric Reliability Council, Juiy 1980.
bSee attached map in fig. 5B-2.

cNet capability is calculated based on the ratio of Net Capability to Installed Capacity as reportad in the *Electric Power Monthly,* U.S. Department of Energy, Energy Information Administration, August 1980.
dCalculations assume that the total available capacity is allocated between baseload and peaking capacity according to the ratio of peaking to baseload capacity within the system. Total available capacity - (net capability) – (peakload).
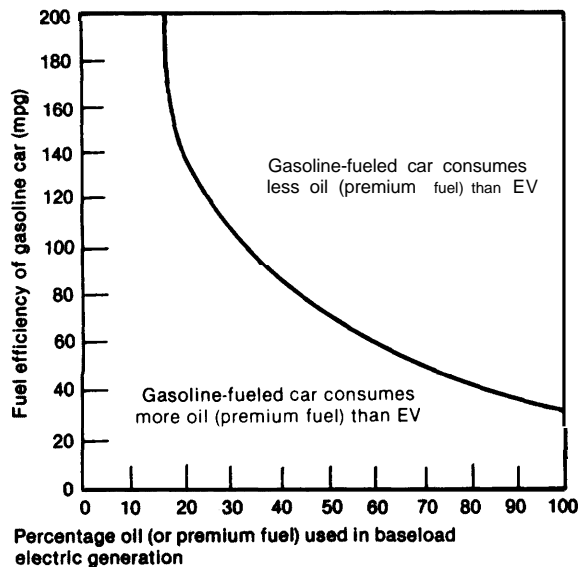
SOURCE: Office of Technology Assessment.

Figure 5B=3.— Illustrative Load Profile With and Without Electric Vehicles
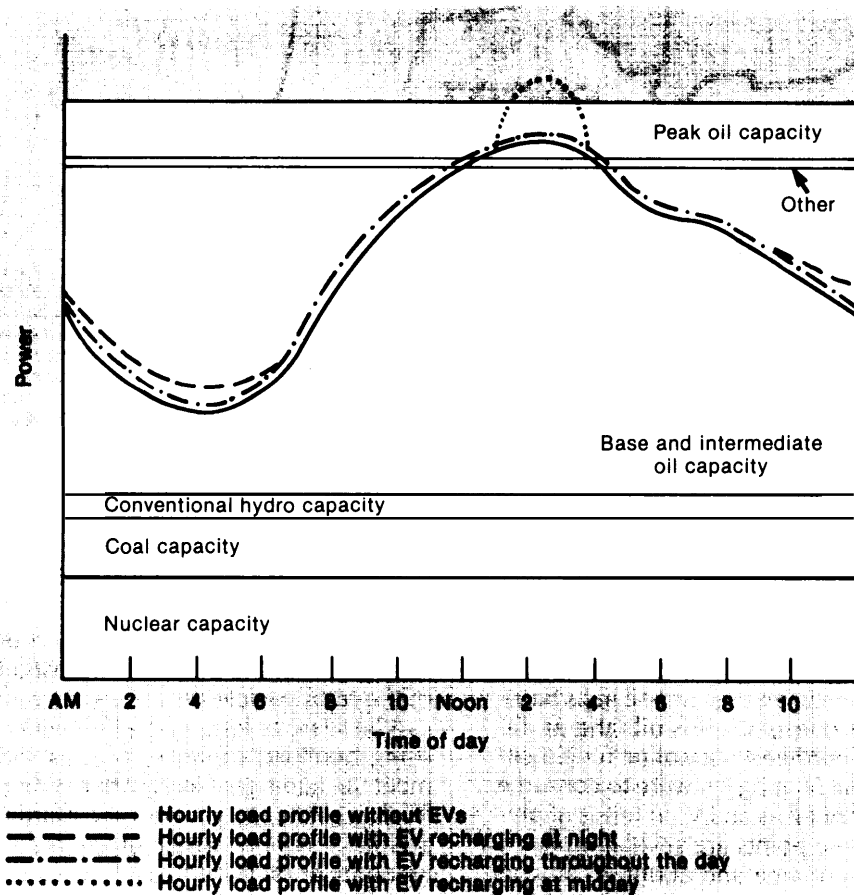
SOURCE: Office of Technology Assessment

Figure 5B-4.— Dependence of Net Oil (premium fuel)
Consumption on Efficiency of Gasoline Car
Replaced and Fuel Used in Baseload Electric
Generation

Percentage oil (or premium fuel) used in baseload
electric generation

SOURCE: Office of Technology Assessment.

introduced, whereas the midcontinent, East-Central,
and Texas regions would utilize the smallest amounts
of oil-fueled baseload capacity.

Petroleum savings accruing from the substitution of
EVs (as opposed to 60-mpg gasoline-fueled vehicles)
for 20 percent of the total vehicle fleet would be ap-
proximately 0.1 MMB/D of oil and 0.07 MMB/D of
premium fuel. The greatest oil savings would be in the
East-Central, Southeast, and West regions. The small-
est amount of oil savings would occur in the Texas,
Southwest, and midcontinent regions; substituting EVs
for small cars in the Northeast would actually increase
oil usage. The greatest premium fuel savings accru-
ing from the substitution of small cars would occur
in the East-Central, Southeast, and West regions. In-
creased premium fuel use would occur in Texas, the
Northeast, and the Southwest. In the future, however,
both oil and premium fuel savings with EVs will in-
crease as utilities switch away from the use of these
fuels for electric generation.

Analyses conducted at the national and regional lev-
els cannot be used to assess the attractiveness of EVs
for individual cities or utilities. For example, individual
utilities may experience significant increments to their
loading, and hence, require a change in baseload ca-
pacity and/or mix of fuel use, depending on the time
pattern of recharging assumed, the percentage of
market penetration, and the technical characteristics
of the battery and charging system (e. g., amperage,
voltage, and efficiency profiles).

Table 5B.2.—Electricity Requirements and Oil Savings With an Electric Vehicle Fleet With 20= Percent Penetration

Region	Total vehicles 1979[a] (x 10⁶)	Electricity capacity required if 20°/0 penetration by EVs [b] as percent of available baseload (percent)			Case A[f] baseload capacity that would be fueled by:		Fuel consumed by fleet of small cars[g] (MMB/DOE)	Fuel saved by replacing 20°A of small cars with EVs[h]	
		Case A[c]	Case B[d]	Case C[e]	Oil (MW)	Premium (MW)		Oil saved (MMB/DOE)	Premium fuel saved (MMB/DOE)
ECAR	19.9	0.15	0.07	0.87	194	200	0.191	0.027	0.027
MAIN	9.2	0.19	0.09	1.14	474	474	0.088	0.011	0.010
MAAC	10.9	0.21	0.11	1.26	203	220	0.105	0.005	0.005
MARCA	5.8	0.16	0.08	0.99	21	29	0.056	0.009	0.008
NPCC	14.7	0.19	0.09	1.13	1296	1296	0.141	−0.004	−0.004
SERC	21.2	0.18	0.09	1.06	554	560	0.203	0.021	0.021
SWPP	9.0	0.19	0.10	1.16	284	846	0.087	0.008	−0.003
ERCOT	6.5	0.10	0.05	0.59	0	716	0.063	0.010	−0.005
WSCC	22.6	0.15	0.07	0.90	887	962	0.217	0.017	0.015
Total	119.8	0.16	0.08	0.98	3913	5303	1.151	0.104	0.074

[a] Ward's *Automotive Yearbook 1980.* For each State served by more than one council, vehicles are distributed among the regions according to the percentage Of the State's residential consumers served by each council as estimated by the State's public utility commission.
[b] EVs require 0.4kWh/mile and are driven 8,000 miles per year.
[c] Recharging occurs over 12 hours during the night (1 Year ≈ 8,766 hours).
[d] Recharging occurs evenly throughout the day.
[e] Recharging occurs over 2 hours at midday
[f] Assumes that th. fuel used t. generate electricity for EVs is in the same percentage as used for baseload generation (See table 5B-1).
[g] Small automobile gets 60 mpg and drives 10,000 miles per year
[h] EV replaces 80 percent of the miles driven by 20 percent of the cars, Negative sign indicates fuel use increases rather than decreases

SOURCE: Office of Technology Assessment.