INTERNATIONAL ENERGY AGENCY

SAVING OIL AND REDUCING CO_2 EMISSIONS IN TRANSPORT

Options & Strategies

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The International Energy Agency (IEA) is an autonomous body which was established in November 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an international energy programme.

It carries out a comprehensive programme of energy co-operation among twenty-five* of the OECD's thirty Member countries. The basic aims of the IEA are:

- To maintain and improve systems for coping with oil supply disruptions;
- To promote rational energy policies in a global context through co-operative relations with non-member countries, industry and international organisations;
- To operate a permanent information system on the international oil market;
- To improve the world's energy supply and demand structure by developing alternative energy sources and increasing the efficiency of energy use;
- To assist in the integration of environmental and energy policies.

**IEA Member countries: Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, Luxembourg, the Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom, the United States. The European Commission also takes part in the work of the IEA.*

ORGANISATION FOR
ECONOMIC CO-OPERATION
AND DEVELOPMENT

Pursuant to Article 1 of the Convention signed in Paris on 14th December 1960, and which came into force on 30th September 1961, the Organisation for Economic Co-operation and Development (OECD) shall promote policies designed:

- To achieve the highest sustainable economic growth and employment and a rising standard of living in Member countries, while maintaining financial stability, and thus to contribute to the development of the world economy;
- To contribute to sound economic expansion in Member as well as non-member countries in the process of economic development; and
- To contribute to the expansion of world trade on a multilateral, non-discriminatory basis in accordance with international obligations.

The original Member countries of the OECD are Austria, Belgium, Canada, Denmark, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The following countries became Members subsequently through accession at the dates indicated hereafter: Japan (28th April 1964), Finland (28th January 1969), Australia (7th June 1971), New Zealand (29th May 1973), Mexico (18th May 1994), the Czech Republic (21st December 1995), Hungary (7th May 1996), Poland (22nd November 1996), the Republic of Korea (12th December 1996) and Slovakia (28th September 2000). The Commission of the European Communities takes part in the work of the OECD (Article 13 of the OECD Convention).

FOREWORD

Last year, the IEA published *The Road From Kyoto*, which examines policies recently implemented in a number of IEA countries to reduce emissions of carbon dioxide in the transportation sector. That book shows that these initiatives have fallen short of offsetting the growth in emissions over the past few years.

Saving Oil and Reducing CO_2 Emissions in Transport: Options and Strategies looks at the future: what additional policies could stem constantly rising oil consumption and CO_2 emissions in the transport sector? This book identifies the potential for new strategies and options, as well as reviews and assesses existing ones, to reduce oil use and greenhouse gas emissions, and help meet targets set in the Kyoto Protocol.

This report on the transportation sector is the first of a broader study whose purpose is to highlight options and strategies in a number of sectors that can improve energy efficiency and cut emissions.

Robert Priddle
Executive Director

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INTRODUCTION AND HIGHLIGHTS

In the transportation sector, total energy use, oil use and emissions of carbon dioxide are closely linked. Petroleum fuels still account for more than 95% of energy use in transport in nearly every IEA country, and oil combustion is a major source of CO_2 emissions. Transport has become the dominant oil-consuming sector in most IEA countries; oil use in the sector has increased steadily over the past 30 years and now represents nearly two-thirds of total IEA oil consumption (Figure 1). Thus, the oil dependence problem is largely a transport problem.

Emissions of CO_2 from road transport increased more than in any other subsector between 1990 and 1999 (Figure 2), for several reasons. The distance traveled by passenger cars and other light passenger vehicles – referred to in this report as light-duty vehicles – has steadily increased

Figure 1

Trends in Total and Transport Oil Consumption in IEA Countries

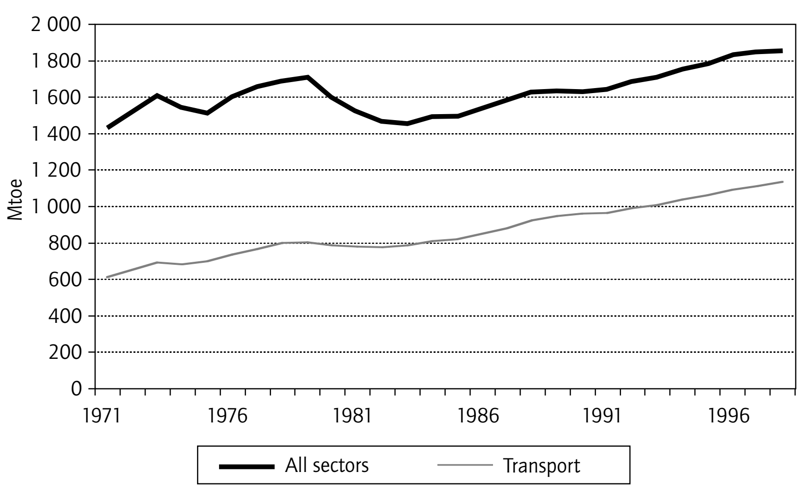
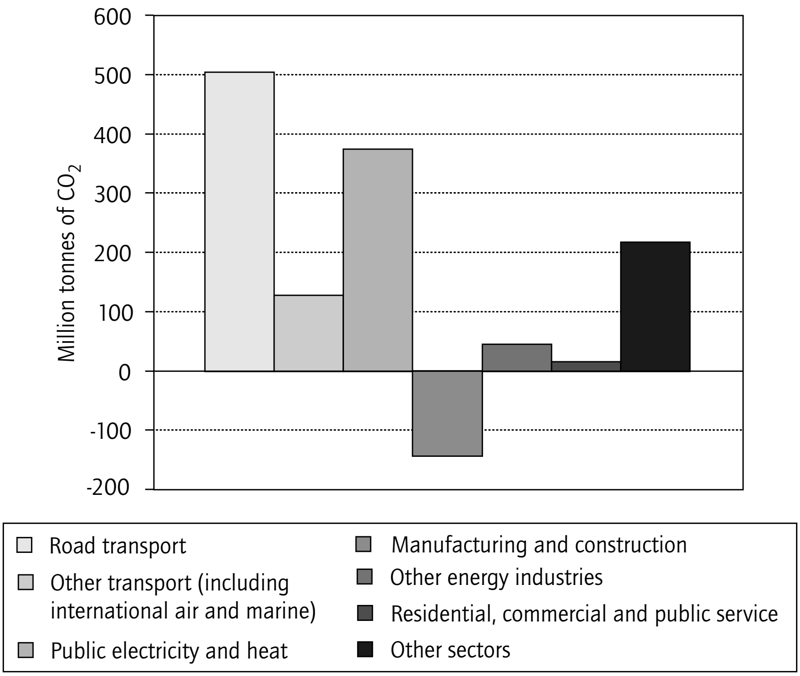


Figure 2

Change in CO_2 Emissions by Sector in IEA Countries, 1990-1999

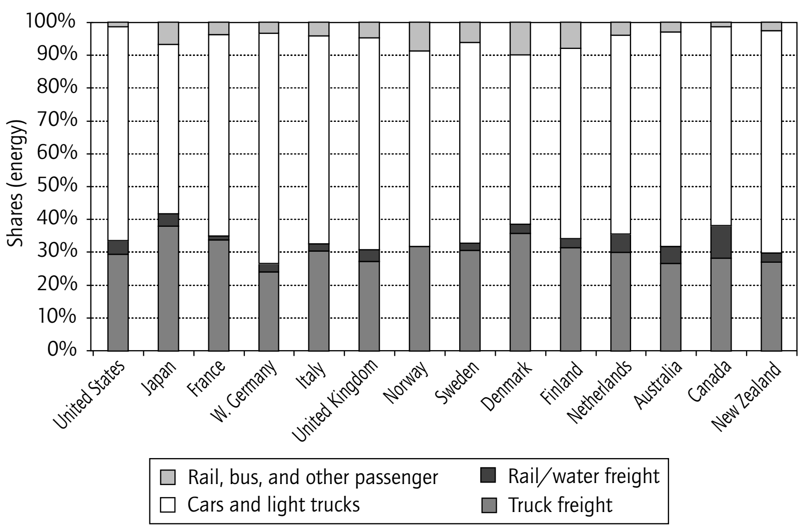


over the period in virtually all IEA countries. Further, the fuel economy of new light-duty vehicles did not improve in any IEA country between 1985 and 1995. (Since 1995 it has sharply improved in European countries and Japan, but not in North America). Although the technical efficiency of light-duty vehicles has improved steadily over the last 20 years, consumer preferences for larger, heavier, and more powerful models have offset most of the efficiency gains, yielding little change in fuel economy. Because strong growth in travel is expected to continue in the future, the light-duty vehicle sector constitutes one of the biggest challenges for reducing oil use and reducing CO_2 emissions. Without new initiatives, we estimate that light-duty vehicle fuel consumption and CO_2 emissions in IEA Member countries will likely rise to 30% above 1990 levels by 2010.

This report addresses light-duty vehicle and other surface passenger and freight transport modes, with a particular emphasis on road transport, because it represents such a large share of energy use within the transportation sector – up to 90% in some countries. (This study does not include air travel). As Figure 3 shows, cars and passenger light trucks account for 50%-65% of transport energy use, freight trucks for 25%-40%, and rail, bus, and water-borne passenger and freight travel for less than 15%, among surface modes of transportation in IEA countries. Accordingly, a 10% decline in fuel use in light-duty vehicle passenger travel is equal to a 6%-7% reduction for the entire transportation sector in most countries; for freight it yields about a 3%-4% reduction and for a small subsector such as passenger or freight rail it results in less than a 1% reduction. Policies that target only the small subsectors must achieve dramatic reductions to cut energy use by more than a negligible amount. Therefore, this report focuses on road transport and addresses water and rail transport only in terms of the

Figure 3

Surface Transport Energy Use Shares by Mode and Purpose, 1995



energy-saving possibilities of shifting the movement of goods from truck to rail and water.

This book examines a variety of options and strategies to reduce oil consumption and emissions of CO_2 in surface transport. For most sectors and policies, the study has drawn on a review of the literature and descriptions of existing policies in IEA Member countries. However, the IEA conducted a considerable amount of original analysis, especially in determining the potential for and cost of reducing fuel consumption and CO_2 emissions as a result of technical improvements to light-duty vehicles. In addition, we designed more than 20 specific options and strategies, based on recent research and examples of best practices, that might be considered as ideas for future use. For each policy example, we calculate how much it could reduce fuel consumption and CO_2 emissions in a typical IEA country, and where possible, we estimate its cost or at least some elements of its cost.

This book includes projections for light-duty vehicle fuel economy, but does not develop a full set of projections or policy scenarios for all the measures discussed in the different chapters. A more thorough set of projections was recently included in the IEA World Energy Outlook 2000 (IEA 2000). These projections included a reference case and alternative case for transport showing the potential impacts of selected measures on reducing fuel use and CO_2 emissions through 2020. In contrast, this volume focuses on providing policy makers with information on the potential for employing a variety of different measures in tackling transport fuel use and CO_2 reductions. However, the estimates presented here are consistent with those used to develop the alternative case projection in the World Energy Outlook 2000.

Most of the options and strategies presented in the following chapters are not radical. They make small changes in the movement of people and goods for modest improvements in fuel efficiency. If well-designed groups of these options are taken together, they could reduce fuel consumption and CO_2 emissions by a substantial amount by 2010. Individually, however, only a few are likely to yield reductions of more than a few percentage points. (We highlight those especially promising individual and groups of policies below). Although most options will not be easy to implement, they are still worthwhile. Most of them can be developed in a manner that is politically acceptable in many countries, or at least not unacceptable. Many measures appear to be inexpensive, or even of negative cost, taking into account the fuel savings and other direct benefits they provide consumers.

One obstacle to reducing oil use and CO_2 emissions in transport is the unresponsiveness of vehicle travel to changes in the travel environment or to the costs of travel. Evidence from past research indicates that a 10% increase in fuel prices usually results in only a 1%-3% decline in travel. Many individuals have few choices about how and how much they travel, once they choose their location of residence and work. If they do have a choice, fuel costs may be a small factor in their decisions. Fuel costs are usually a low percentage of variable travel costs, which also include parking, tolls and vehicle maintenance. (Variable costs can also affect travel, perhaps of a similar magnitude as changes to fuel costs). Increases in fuel costs, however, may encourage the purchase of vehicles with better fuel economy or, possibly, switching to alternative fuel vehicles that can run on a less expensive fuel. Therefore, fuel consumption and emissions of CO_2 may be more responsive than travel to changes in fuel prices. We consider all of these factors in estimating the effect of the policy options on oil consumption and CO_2 emissions.

IEA's estimates of these effects and the costs of implementing the policy options are subject to considerable uncertainty. We do not attempt to estimate the full cost per ton for CO_2 reductions; instead we identify the types of costs and benefits of each policy. Cost components that are well known or easily calculated, such as for some technologies and for the value of fuel savings, are estimated. We point out cases where the fuel savings alone appear large enough to offset the direct costs of a measure. But such a comparison is incomplete, since almost all transport policies have important societal effects that are difficult to quantify: on safety, traffic congestion, travel time, emissions of air pollutants, and even on lifestyle. Estimating all of these effects, which vary from location to location, and country to country, has proven difficult and is the subject of debate and on-going research. Without taking them into account, however, any specific estimate of the cost of reducing fuel use and CO_2 emissions may be misleading. Conversely, since governments often implement transport policies primarily to have effects other than on oil use or CO_2 emissions (e.g. congestion reduction, economic development, air quality improvements), it is all the more important to quantify the potential impacts of such measures on fuel use and CO_2, since these impacts can be important.

The options and strategies are developed with national governments in mind, but recognize that many transport initiatives are best undertaken by regional or local governments. This is particularly true for the policies that aim to modify the patterns of urban passenger travel, for example through roadway design, provision of transit services, and support for non-motorized modes of transport like bicycles. For those options, we identify approaches that national governments can take to encourage action at a local or regional level. The IEA also takes the somewhat unconventional approach of avoiding discussion of one of the key energy-saving measures traditionally implemented by national governments in the transport sector: fuel taxes. This report seeks to offer alternatives that can complement or substitute for fuel taxes, which are increasingly unpopular.

Highlights: Promising Strategies

Of the strategies and options in this book, most offer modest oil and CO_2 reductions when implemented alone, typically in the range of 1% to 3%. A few offer bigger reductions. However, when properly combined, it is not difficult to construct a package of measures that can result in savings of 10% or more. This section reviews several of the most promising individual measures, and the next section covers how individual measures may be combined to best advantage.

Improving Fuel Economy through Technical Changes: Much cost-effective technology exists that can be deployed on light-duty vehicles to improve fuel economy. This appears to be one of the few individual measures that can achieve large reductions in oil use and CO_2 emissions by 2010, and at potentially very low cost. IEA analysis finds that these available cost-effective technologies could reduce average fuel consumption for new cars as much as 25%-30% by 2010 in most countries (compared to what it may be without new technologies) and probably by at least 20% in every country, even those with relatively low fuel prices such as the United States. A new report by the US National Research Council (NRC 2001) estimates a similar cost-effective potential improvement for the US. We estimate that by 2020, use of cost-effective technology plus aggressive adoption of advanced propulsion technologies such as hybrid-electric and fuel-cell systems could reduce new car fuel consumption by more than 40%. Fuel economy for the total stock of light-duty vehicles would improve more slowly, as it is replenished by the new, higher efficiency models. By 2020, stock average fuel consumption and CO_2 emissions could be cut by up to 30%, and by more than 40% by 2030. Greater use of diesels could contribute yet another 5%-15% reduction in fuel use, especially in North America where the current diesel market share is quite low.

Policy intervention is needed, however, to encourage deployment of new technology at a maximum rate, and to ensure that its fuel savings are not lost through sales of larger, heavier, and more powerful vehicles – a fuel-hungry trend in most IEA countries over the past 15 years. Measures that can curb this trend include vehicle purchase fees, rebates, and other incentives based on fuel economy or the presence of particular advanced technologies. Even a modest fee would send strong price signals to both consumers and vehicle producers, predisposing them toward higher efficiency vehicles. Countries with vehicle purchase fees based on added value could replace some or all of this fee to one linked to fuel economy, rendering a new fee unnecessary.

Promoting On-board Technologies that Improve Fuel Economy: These technologies include diagnostic equipment that can identify and report vehicle problems to drivers, information systems that can assist drivers in maximizing fuel economy, and automated systems that can improve fuel economy by controlling certain vehicle functions. Advanced cruise-control systems can reduce fuel use and increase safety, not only by maintaining steady speeds but also through smoother acceleration and deceleration. Other technologies such as econometers, which report rates of fuel consumption to the driver in real time, send signals about which driving behaviors yield fuel savings. If governments require the technology or provide financial incentives to consumers, and car companies increase the availability of on-board devices, fuel consumption and emissions of CO_2 for light-duty vehicles could decline 3%-5% by 2010. The costs of these devices are likely to be more than offset by their fuel savings. The Netherlands has taken the lead in this area by offering financial incentives to manufacturers and consumers to add certain information systems to vehicles.

Toll Rings and High Occupancy/Toll Lanes: While most economists strongly support roadway pricing to efficiently reduce traffic congestion, most communities that have considered it have rejected this option. Drivers are not yet convinced of the benefits of tolls while the costs are all too apparent. Some innovative toll systems, however, may be more politically acceptable. These include toll rings and high occupancy/toll (HOT) lanes. Toll rings are sets of tollways placed around a city periphery that charge for access to the center. They are an example of cordon pricing – charging for vehicle movement between different zones. The charge for access within the toll ring compels drivers to consider travel options other than single-occupant vehicles. The country with the most toll rings, Norway, has shown that they can be implemented in a manner acceptable to the public. Clearly linking revenue from toll rings to improvements to the transportation infrastructure and transit service can strongly increase public acceptance.

Although most analyses of road pricing and toll rings have not looked at their effects on fuel use or emissions, a European Commission modeling study found that cordon pricing systems for Athens and Lyon could result in a 14% decline in car travel and an 8%-10% decrease in CO_2 emissions. The IEA estimates that if governments adopt an incentive for all major metropolitan areas to implement cordon-pricing systems, they could reduce fuel consumption and emissions of CO_2 for light-duty vehicles nation-wide 3%-6% by 2010.

High Occupancy/Toll lanes, or HOT lanes, have become popular in some parts of the United States to increase travel options for commuters and collect tolls on existing highways. So far, HOT systems have been created by adding electronic tolling to High Occupancy Vehicles (HOV) lanes, which are restricted to vehicles with at least two or three passengers. By paying a toll, low-occupancy vehicles gain access to the corridor. Adding tolling has not only increased the use of previously underutilized HOV roadways, but also more importantly has created a public sense that drivers can buy their way out of traffic congestion. Eventually, as the public becomes familiar with HOT lanes, adding tolls to other existing highways may become politically possible. Converting HOV to HOT lanes, or creating new HOT lanes, might not reduce CO_2 emissions immediately since they essentially increase roadway capacity and could reduce vehicle occupancy. Rather, conversion of HOV into HOT lanes could represent an important step towards building public acceptance of electronic tolling and roadway pricing in general.

A National Parking Tax and Cash-out: The availability and cost of parking are major factors in individuals' decisions to drive or choose another mode of travel. A change from free to priced parking, even a low price such as USD 1.00 per hour, adds more to the cost of many trips than big increases in fuel cost, and encourages a reduction in vehicle trips. Thus, parking pricing can be a powerful tool. Measures that restrict the amount of parking or that increase fines and enforcement also send strong signals to drivers. Parking measures receive strong public support in many cities, especially in places where parking revenue is earmarked for local community projects such as beautification. In some countries such as the United States, where free parking is abundant, pricing it may be politically and logistically difficult. One promising option is to encourage employers to offer employees the choice between free parking and a cash subsidy for other modes of commuting travel. By *cashing out* their free parking spaces, employees can save money and commute by other means such as carpooling or bicycling. In California, firms with cash-out programs measurably reduced car travel and emissions of CO_2. A cash-out policy or increased parking fees could minimize the number of parking spaces needed in new buildings, which could increase land-use density and in turn also reduce travel. A national parking tax of USD 1.00 per hour (USD 3.00 maximum per day), combined with support for parking cash-out programs, could yield reductions in travel, fuel use and CO_2 emissions for light-duty vehicles of 4%-7% by 2010. This reduction might increase over time as people, businesses and localities factor the tax into decisions about location and land use.

Low Greenhouse Gas Alcohol Fuels: Chapter 4 shows that while a variety of alternative fuels could substitute for petroleum, relatively few also promise large reductions in greenhouse-gas emissions – aside from alcohol from cellulosic crops. Since they can run in conventional vehicles, alcohol fuels have other important advantages: they do not require major investments in new types of vehicles or in a new system of fuel stations. They can be blended with gasoline up to 15%-20% by volume and used in current vehicles, and can be distributed through the existing refueling system. Alcohol from cellulosic feedstocks – in contrast to most of today's alcohol fuel, produced from starchy crops – can take advantage of low-energy growing and conversion processes that substantially reduce its *full fuel cycle* greenhouse gas emissions, up to 90% lower than gasoline. The primary disadvantages are the vast amounts of land required for growing the crops, and the high price of growing and converting the crops to alcohol. In recent years, however, yields per acre have increased and costs have fallen, and research continues in these areas in IEA countries. While these fuels may never replace petroleum fuels completely, they could eventually replace up to 10% in some countries and thereby reduce CO_2 emissions by up to nearly 10% – a larger reduction than for many other options. Alcohol probably can displace only a few percent of gasoline by 2010 in most IEA countries, but at least 5% by 2020 in many countries. For light-duty vehicles, this would yield a 3%-4% reduction in CO_2 emissions.

Telematic Systems for Freight: The increased availability of computer systems for more efficiently managing trucking and local freight delivery are creating new opportunities for saving fuel. These same technologies, however, have also allowed for *just-in-time* methods of inventory that have also led to increases in truck travel. To counteract that, trucking firms are just beginning to take advantage of scheduling and routing software to combine deliveries and reduce empty truck (*backhaul*) travel.

Governments can help improve logistics systems for urban areas by encouraging, or directly investing in, advanced driver and network information systems, co-operative freight transport systems, and public logistics terminals. While national governments do not usually make direct investments in urban infrastructure, they often provide funding for important projects. It makes sense to fund and co-ordinate improvements in urban logistics nationally, in part to ensure that systems are compatible throughout a country.

Estimating the fuel savings resulting from better logistics management is difficult. If a strategy is developed that increases average truck load factors by 10% in major urban areas, however, then average fuel use for freight trucks would decline 2%-3%. This can usually be achieved at a low or negative cost, since it comes nearly entirely from increased operating efficiency in the freight sector.

Developing Policy Packages

A key aspect to developing effective fuel saving, CO_2 emissions reduction transport policies is to integrate individual policies and measures into packages that benefit from a *synergistic* interaction among the components. It is also important to avoid implementing policies that work at cross purposes and negate the benefits of other policy elements.

Three types of promising policy packages are presented in Table 1. The basic approaches are: a) a focus on private vehicle travel reductions (and increased uses of transit and non-motorized travel modes),

b) increased vehicle efficiency and use of non-petroleum and/or low-carbon fuels, and c) a combination of the first two that selects policies from each group that work well together. The policies mentioned in the table for each group serve to reinforce each other and in some cases provide synergistic benefits, with the net impacts adding up to more than the sum of the impacts of individual policies within the set.

As the table shows, one major difference between the three groups is the type of impact they have: policies to improve vehicle fuel economy will tend to increase travel levels (by lowering the cost of driving) and therefore, as a group, generally work in a different direction than policies that are directly targeted toward vehicle travel reductions. Further, policies that effectively increase roadway capacity or improve traffic flow may *induce* increased travel. However, it may be possible to eliminate the mixed signal by using pricing to maintain travel costs. For example, increases in fuel prices can be used to maintain the cost of driving in the case of increased vehicle efficiency, and increased fuel or roadway prices can be used to maintain the cost of travel in the case of traffic flow improvements or capacity expansion.

Estimating the impacts of specific packages is difficult and is for the most part outside the quantitative scope of this book, but one example policy including several travel reduction measures is provided in Chapter 3. This package, including transit improvements, parking restrictions and increased prices, and promotion of walking and bicycling, could provide up to a 16% reduction in light-duty vehicle fuel use and CO_2 emissions by 2010. A package of policies that adds significant amounts of low greenhouse-gas alternative fuel (such as cellulosic ethanol) to the fuel economy improvement measures mentioned above could reduce oil use and CO_2 emissions by over 30% by 2010. A well designed (and aggressive) combination of travel reduction and fuel economy improvement packages could therefore yield reductions on the order of fifty percent.

Table 1

Grouping Policies for Reinforcing Effects: Three Possible Packages

Vehicle Travel Reduction	Reducing Vehicle Fuel Use /CO_2 Emissions	Mixed Approach
Policies that reduce vehicle travel demand and provide alternatives to vehicle travel, including: • Pricing of vehicles, fuels, and roadway usage to discourage vehicle ownership and driving • Land use changes and related measures that promote transit and non-motorized travel • Improvements in transit service and incentives for increased transit ridership • Provision of alternatives to driving through telematic measures such as incentives for telecommuting and teleshopping.	• Increased new car and light-truck vehicle efficiency through technical measures, including greater adoption of near-term and "next-generation" technologies • Encouraging consumer purchases of the most efficient vehicles available and discouraging purchases of ever-larger, more powerful vehicles • Optimizing on-road efficiency through capacity enhancements, traffic flow improvements, vehicle maintenance and driver education • Promoting alternative fuels that reduce oil use, increase overall energy efficiency, and reduce CO_2 (and other GHG) emissions.	Elements of the first two approaches that are complementary, i.e. measures that encourage both decreased personal vehicle travel and increased efficiency of travel. The mixed approach should also include: • Fuel pricing increases that offset reduced cost-per-kilometre of travel from efficiency improvements. Differential price increases by fuel type can be used to simultaneously encourage selected alternative fuels. • Avoiding roadway capacity enhancements, traffic flow improvements, and related measures that encourage more vehicle travel (the "induced demand" effect).
Advantages: Lower vehicle travel will reduce CO_2 as well as pollutant emissions, lower societal costs associated with vehicles (accidents, traffic law enforcement, etc.). Many argue that such an approach provides other societal benefits in terms of "livability" from communities less dominated by cars and roadway infrastructure.	**Advantages:** Relatively large reductions in fuel use and CO_2 emissions are possible from small increases in new vehicle and on-road fuel economy. Such reductions are often inexpensive since fuel savings offset much or all of the cost of the vehicle improvements.	**Advantages:** Takes many of the best elements of first two approaches. Maximizes the synergistic and reinforcing impacts by removing the elements that run at cross purposes, or by building in elements to prevent this from occurring.
Disadvantages: Aggressive policies are needed to achieve significant reductions in travel. Travel responsiveness to price increases and other anti-car policies is quite low. Land use measures may take a long time to have an impact. Important opportunities for fuel savings and CO_2 emission reductions from vehicle efficiency improvements may be missed.	**Disadvantages:** Some technologies may require long lead-times to penetrate the market (e.g. fuel cells). All measures that improve fuel economy reduce the cost of travel and are likely to yield some "rebound effect", i.e. higher travel levels. Measures to increase capacity or traffic flow may also trigger more travel that could wipe out much of the energy savings /CO_2 benefit.	**Disadvantages:** May be difficult to implement a comprehensive package – transport policy is typically implemented in bits and pieces.

1 IMPROVING FUEL ECONOMY THROUGH TECHNICAL CHANGES TO NEW LIGHT-DUTY VEHICLES

The first part of this chapter briefly reviews recent trends in new light-duty vehicle fuel economy[1]. The second part, based on new IEA analysis, looks at the potential for near-term increases in fuel economy through the deployment of conventional technologies. The third part estimates the potential for longer-term improvements in fuel economy using advanced technologies, particularly gasoline/electric hybrids and fuel-cell vehicles[2]. The fourth part examines policies that could help to realize the potential of these technologies for saving fuel.

Trends in Fuel Economy for New Light-Duty Vehicles

Fuel economy for new light-duty vehicles[3] has been nearly flat in most IEA countries since 1980, except for important improvements in the early 1980s and, in European countries, in the late 1990s (Figure 1.1). It appears that the voluntary commitment by European manufacturers

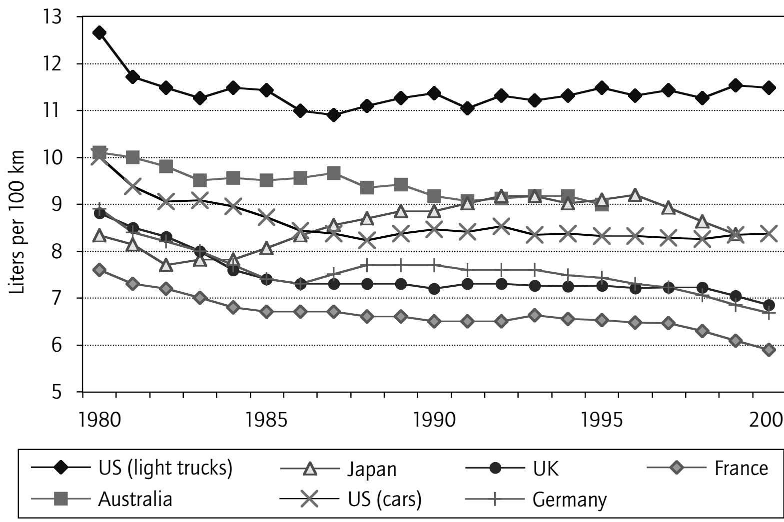
1. Fuel economy refers to both the European measurement of fuel consumption in liters per 100 km traveled and for the United States measurement in miles per gallon (MPG). However, for a given improvement, the percentage change expressed in liters per 100 km is always less than in MPG. For example, a 50% increase in MPG is equal to a 33% reduction in liters per 100 km.

2. Gasoline/electric hybrids are vehicles with electric drive systems that are powered by internal combustion and batteries. Fuel cell vehicles have drive systems powered by fuel cells, which are electrochemical devices that produce electricity through a chemical process involving the production of water from hydrogen and oxygen.

3. Light-duty vehicles include cars and other light passenger vehicles such as minivans and sport utility vehicles.

Figure 1.1

New Car Fuel Economy in Selected IEA Countries, 1980-2000[4]



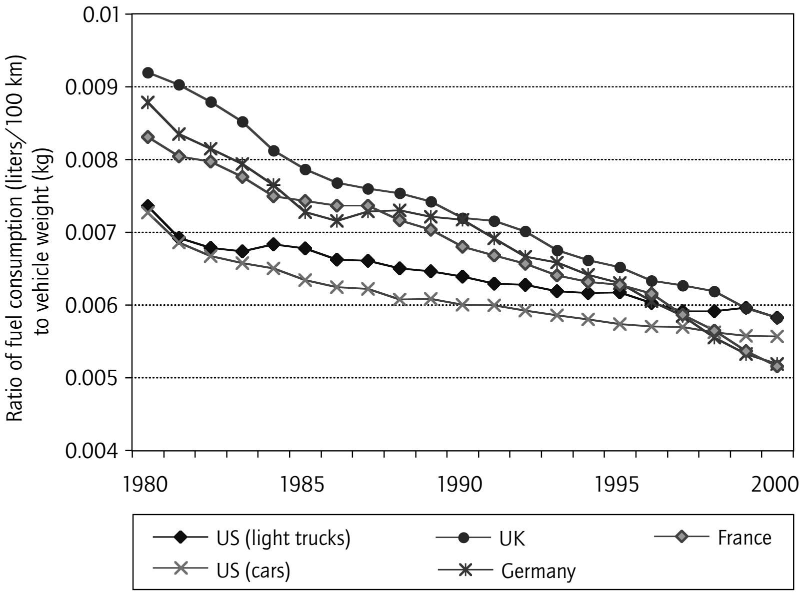
to reduce CO_2 emissions in new cars by 25% by 2008 has begun to take effect: while car and light truck fuel economy in the United States remained flat in the late 1990s, it has sharply improved in most European countries since 1995. Whether this recent trend will continue is unclear, however, and is a central concern of this chapter.

Although new light-duty vehicle *fuel economy* has been flat for much of the last 20 years, these vehicles have become steadily more *efficient* over the period. For example, their energy use per unit weight has dropped in every country since 1980 (Figure 1.2). These efficiency gains, however, have been offset by increases in average vehicle weight (Figure 1.3). A similar trade-off has occurred between vehicle energy

4. Data are for gasoline and diesel vehicles, with 1997-2000 European data adjusted to the older (pre-1997) test cycle for comparative purposes; fuel consumption is about 9% higher with the new EU test cycle.

Figure 1.2

Trends in New Car Fuel Use per Unit Weight



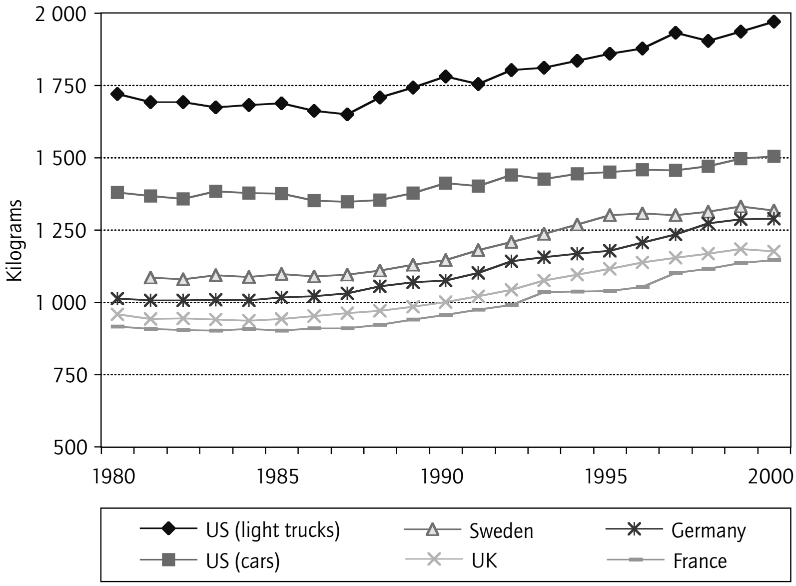
use and vehicle engine power. Energy use has declined per unit power, but power (usually measured as horsepower or kW) has increased, offsetting the efficiency gain.

During the same period, the efficiency of the total stock of light-duty vehicles (including new and existing vehicles) in most IEA countries continued to improve, since the fuel economy of new cars was better than that of the cars they replaced. However fuel consumption increased steadily since growth in travel by light-duty vehicles was greater than the improvement in average stock efficiency. Since travel growth is expected to remain strong in the future[5], this sector constitutes one of the biggest challenges for reducing oil dependence and meeting the Kyoto targets by 2010.

5. See Chapter 3 for a full discussion of trends in light-duty vehicle travel.

Figure 1.3

Trends in New Car Weight



Improving Fuel Economy with Conventional Technologies

This section presents IEA's analysis of the potential for increased fuel economy in Denmark, Germany, and the United States. These countries were chosen because good data are available and because their light-duty vehicle sectors are different – not only in terms of the types of vehicles driven, but also how often and how far – and therefore so is their fuel use and emissions of carbon dioxide. Also, Germany and the United States manufacture vehicles while Denmark does not. By choosing three countries with different characteristics for this analysis, the results can be generalized to other IEA countries.

In all three countries, CO_2 emissions from road transport represent an important share of the total: for 1996, they were nearly 25% of the total in the United States, about 18% in Germany and about 15% in Denmark. Light-duty vehicles account for well over half of CO_2 emissions from road transport in each of these countries.

The on-road fuel economy of each country's light-duty vehicle stock continued to improve in the 1990s in Denmark and Germany, but stopped improving in the United States (Figure 1.4). This trend reflects the stagnation of fuel economy improvements in new vehicles in the United States (Figure 1.5) and the improvement in average fuel economy for the vehicle stock to nearly that of new vehicles. This trend is also due to the increased popularity of passenger light trucks (including minivans and sport utility vehicles), whose fuel consumption is substantially higher than that of cars (Figure 1.5). Passenger light trucks accounted for almost half of vehicle sales in the United States in 1998, but less than 10% in Germany and Denmark (Figure 1.6).

Even though average fuel economy for all new light-duty vehicles is different in each country, fuel economy for vehicles of a similar size is comparable. For example, for subcompact and compact cars, the only two market classes with substantial sales in all three countries, the differences in average rated fuel economy are small, less than 1 liter per 100 km (Figure 1.7). These data indicate that much of the variance in fuel economy of new light-duty vehicles among the three countries is due to differences in vehicle size rather than fuel economy.

Current Market Penetration of Fuel Economy Technologies

The IEA also assessed the fuel economy technologies present on new vehicles in the three countries and found some strong similarities, as well as a few important differences. We began by identifying the extent to which specific technologies (see box) are present on the major 1998

Figure 1.4

Light-duty Vehicle Stock On-road Fuel Economy Trends

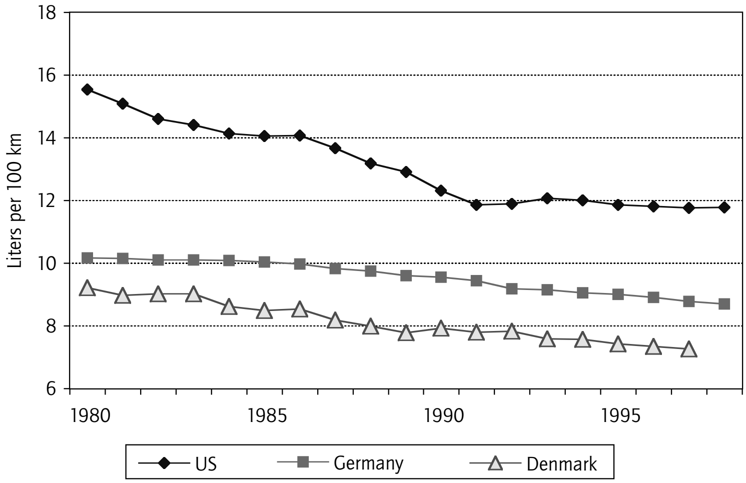
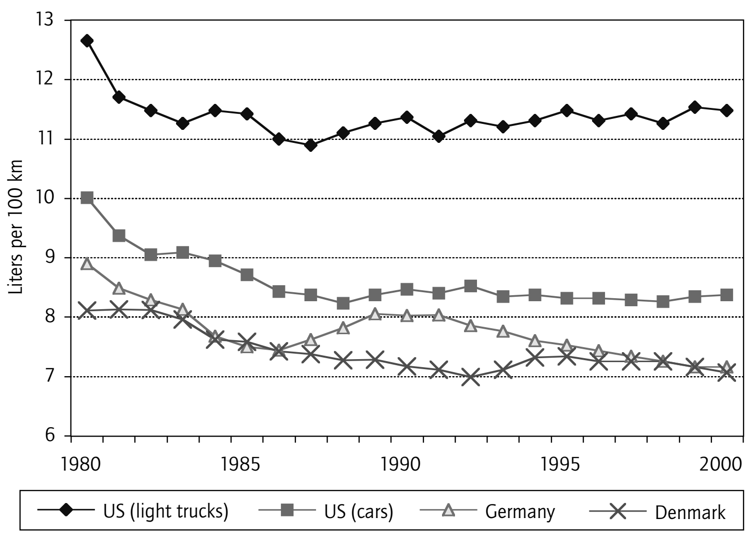


Figure 1.5

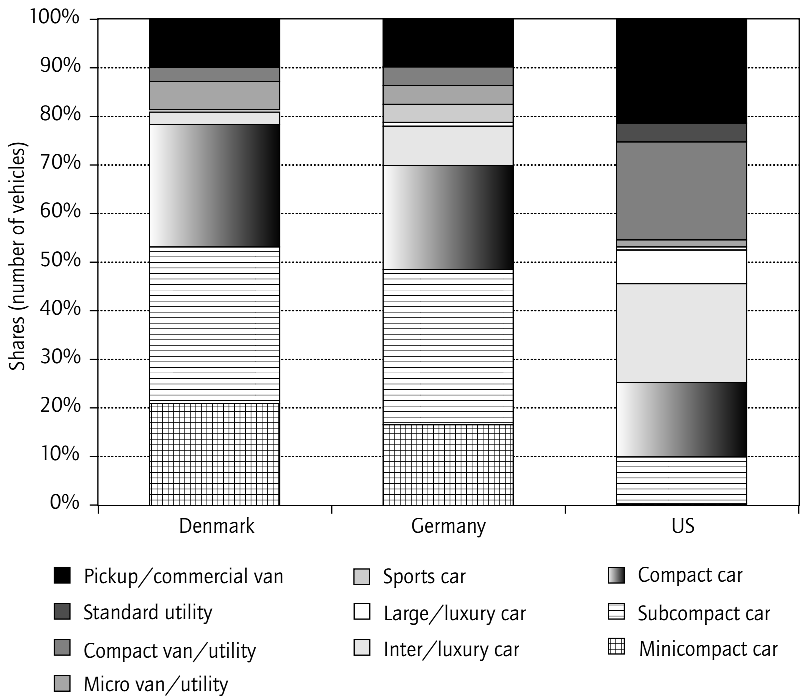
New Light-duty Gasoline Vehicle Fuel Economy Trends[6]



6. For continuity of presentation, fuel economy data for Denmark and Germany, 1997-2000 is converted to the EU test cycle by adjusting downward by 9%.

Figure 1.6

Light-duty Vehicle Sales Shares by Market Class, 1998[7]



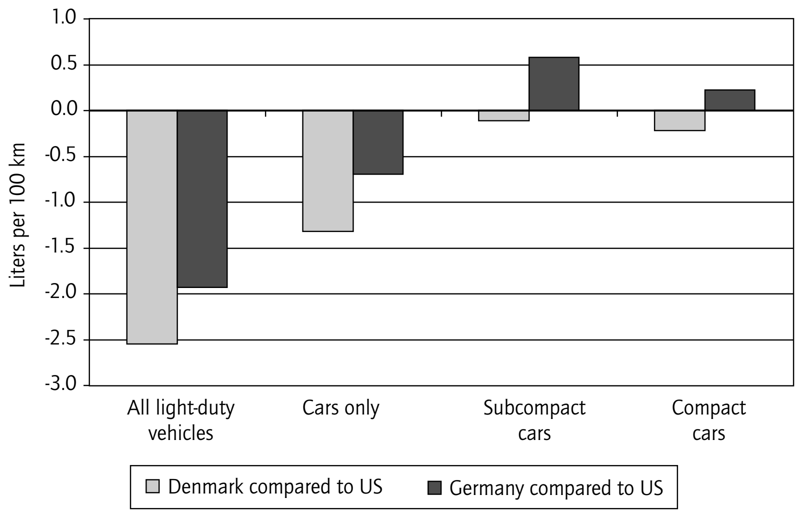
vehicle models sold in each country. Focusing on the top-selling models in each market class in each country, technologies present on each model were identified, and data on each model's sales and market share were used to estimate the market penetration of each fuel economy technology. Figure 1.8 shows those estimates for compact cars in 1998. (A more detailed report of the fuel economy technologies and the methods used in analyzing their market penetration is available on the IEA web site[8]). For compact cars, the market

7. The data for the United States are primarily for passenger vehicles as they exclude business fleets; the pickup, van and utility data for Germany and Denmark include some small cargo vehicles.

8. Policies and Measures to Mitigate Greenhouse Gas Emissions: Transportation Options (Light-Duty Vehicles) Technical Appendix, available at http://www.iea.org/envissu/p&m.htm.

Figure 1.7

New Car Fuel Economy Comparison, Overall and for Selected Market classes, 1998 Model Year

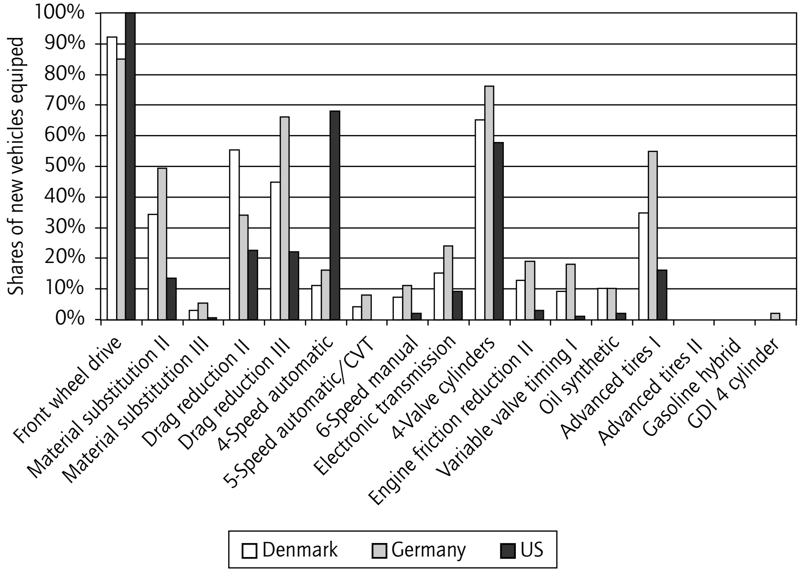


penetration for various technologies in 1998 is similar: in Germany it is typically slightly higher than for Denmark, whose level is slightly higher than that of the United States (with typically less than 10 percentage point difference among the three countries). Wider differences are seen for a few technologies like drag reduction and advanced tires. The most marked differences are for technologies specific to either standard or automatic transmissions, which have very different market shares in the three countries. Differences among subcompact and intermediate size cars are similar to those for compact cars. Larger differences exist in some other market segments, especially in niche classes like sports cars. But overall, technology levels in the automobiles of the three countries are remarkably similar.

The level of fuel economy technology for these countries is different in one other respect: in Denmark and Germany, and the rest of Europe, diesel engines typically have a large and often growing share of the

Figure 1.8

Estimated Technology Market Penetration, 1998 Compact Cars



light-duty vehicle market. Diesel engines usually have greater fuel economy than gasoline engines. Because of their popularity in Europe, manufacturers may actually have less incentive to add more technologies to gasoline vehicles to improve their fuel economy, as buyers keen to maximize fuel economy tend to choose diesels.

Given the substantial differences in fuel prices between Europe and the United States one might expect more differences in technology. Why are they so similar? One reason is that the vehicle market is becoming increasingly global, and many of the same models are sold in both the United States and in Europe. Also, since Europeans drive smaller cars, on average, than North Americans, and drive fewer kilometers per year, much of the increased cost of fuel is offset through fuel savings due to vehicle size and travel reductions, perhaps removing some incentive to further increase fuel economy through technology improvements.

Finally, application of new technologies may be driven more by considerations of vehicle power and performance than by fuel economy, and this incentive may be similar in the United States and Europe.

Technologies to Improve Fuel Economy

Maximum fuel economy (or minimum fuel intensity) is achieved by minimizing propulsion energy requirements and maximizing the efficiency of the power train.

Techniques to reduce propulsion energy requirements include reducing vehicle weight, streamlining the vehicle shape, reducing vehicle frontal area, and reducing the rolling resistance of tires.

This analysis considers a number of available technologies to reduce propulsion energy requirements:

- *Two levels of aerodynamic improvement that involve streamlining bodies to reduce the drag coefficient.*
- *Two levels of weight reduction through materials substitution, including increased use of aluminum, plastics and lightweight composite materials.*
- *Reduced engine friction through the use of advanced lubricants and synthetic oils.*
- *Reduced tire rolling resistance through the use of harder materials, advanced tread designs, and other techniques.*

Technologies considered that improve engine and drive-train efficiency include:

- *Setting combustion speed as close as possible to optimal load and constant volume.*
- *Increasing the compression ratio or expansion ratio to improve thermodynamic efficiency.*
- *Using variable valve timing to minimize the throttling loss associated with part-load operation.*
- *Turning the engine off during periods of zero power demand (idle and deceleration).*

- *Reducing engine friction and parasitic losses.*
- *Recapturing and using exhaust heat energy.*
- *Improvements to transmission such as 6-speed manual and 5-speed automatic. Other advances such as electronic transmissions and continuously variable transmissions are coming into the market.*

Also taking advantage of the above engine drive-train technologies are "new generation" engines such as gasoline direct injection and hybrid-electric systems, which are available in some markets. This analysis includes both technologies, though the type of hybrids considered here run on gasoline and recharge their batteries with the engine and through regenerative breaking. They would not be rechargeable via the electric grid.

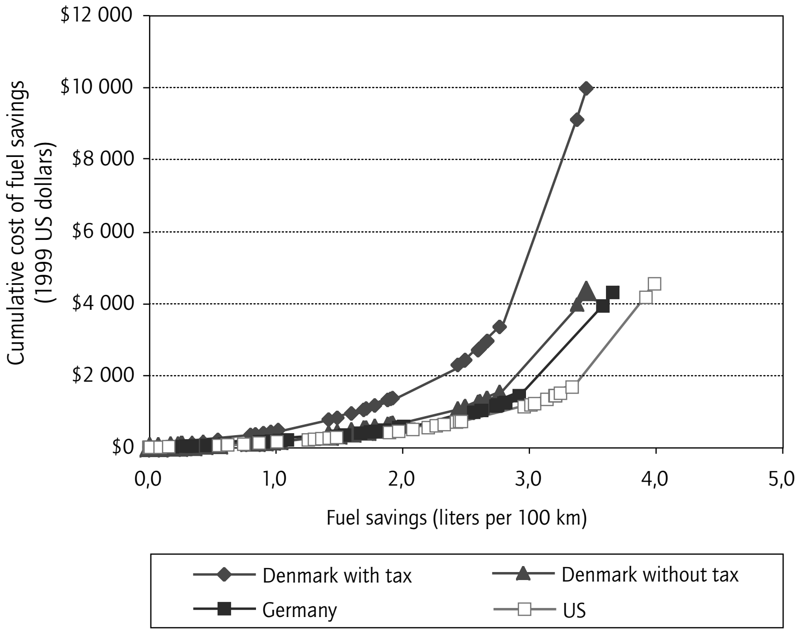
Estimates of Fuel Economy Potential and Cost

Next, the IEA analyzed the potential for improving fuel economy in each country, based on estimates of cost and fuel savings for each technology[9]. A supply curve was developed to estimate the effects on fuel economy and cost of applying one technology at a time, taking the most cost-effective ones first, to a new vehicle with an average (1998) technology level (Figure 1.9). The curves in the figure illustrate the cumulative cost of achieving reductions in new car fuel intensity, taking into account synergies and other interactions between different technologies when they are used together on vehicles.

9. Estimates of technology potential and cost were provided by Energy and Environmental Analysis, Inc. (EEA) and are found in the technical appendix on the IEA's web site at www.iea.org/envissu/p&m.htm. There is some uncertainty regarding any such estimates, as reflected in the considerable variation in the literature (particularly for the technology cost estimates). However, the EEA estimates fall near the middle of the range of recent estimates. See, for example, Austin, Thomas C., et al., "Alternative and Future Technologies for Reducing Greenhouse Gas Emissions from Road Vehicles", prepared for the Canadian Transportation Table Subgroup on Road Vehicle Technology and Fuels, Sierra Research Inc. under subcontract to Senes Consultants Limited, July 8, 1999; Sierra Research 1999, Decicco and Ross 1994, John, and Marc Ross, "Improving Automotive Efficiency", Scientific American, December, 1994; and Energy and Environmental Analysis, "Fuel Economy Potential of Light-Duty Vehicles Post 2015", for the United States Office of Technology Assessment, 1995.

Figure 1.9

Fuel Economy Cost Curves: Comparison of Countries



For this exercise, the basic cost of each technology was assumed to be similar in each country, with some adjustments made to reflect differences in the average 1998 pretax vehicle prices. As Figure 1.9 shows, the cost curves for the United States, Germany and Denmark (not including tax) are similar. The curve for the United States shows slightly greater fuel economy improvement (fuel savings) at a given cost. That is mainly because US vehicles are larger than in Germany or Denmark. There are also differences in how far one can go along each curve until the cost of the next improvement is higher than the value of the estimated fuel savings. However, there exists considerable potential for cost-effective technical improvements to fuel economy in each country, even at relatively low fuel prices, over the next 20 years[10].

10. "Cost-effective" means that the cost of a technology deployed on a vehicle will be offset by its future fuel savings, which in this analysis is calculated using a four-year payback period with a 10% discount rate.

Figure 1.9 also shows a second cost curve for Denmark. This includes Denmark's high value-added tax applied at registration to the purchases of new vehicles. This tax can be as much as 180% of the price of the car. Since the tax increases with the price of the vehicle, additional technologies that raise a price of a vehicle are, in essence, taxed at the marginal rate. While the tax very effectively dampens demand for new cars, it also more than doubles the effective cost of fuel economy technologies. This may in part explain why many technologies have achieved greater penetration in Germany than in Denmark (as shown in Figure 1.8). Denmark recently has begun to modify its tax structure by introducing a tax reduction on vehicles with very low fuel consumption, which will help to reduce the distortions resulting from the valued-added tax.

Scenarios for Fuel Economy and Technology Cost through 2020

As reflected in the cost curves, the IEA's analysis suggests that a considerable amount of technology is available to improve vehicle fuel economy in each country. However, recent trends toward larger and more powerful vehicles, if they continue, could offset some or all of the fuel economy improvements promised by the new technology. To explore these possibilities, three scenario projections through 2020 for light-duty vehicle fuel economy in each country were developed (Figure 1.10).

All the scenarios assume that cost-effective technologies will fully penetrate the market eventually. However, a number of real-world factors are taken into account that may slow the rate of adoption, such as efficient timing of investments during vehicle product cycles. The first scenario looks at the effect of the introduction of cost-effective technologies on fuel economy, assuming that new vehicles continue to grow larger, heavier, and offer faster acceleration. The second scenario assumes the same rate of market penetration of technologies, but holds these vehicle attributes at model year 2000 levels. For the third scenario, vehicle attributes are held in check, but a number of additional technologies enter the market that are cost-effective at higher fuel prices or at a tax reflecting a value of USD 100 per ton for the reduction of CO_2 emissions.

The first two scenarios illustrate that fuel economy in the future will depend in part on the kinds of vehicles consumers buy. The second scenario shows that cost-effective technology could reduce new car fuel consumption per kilometer by 25% or more by 2010 from its 1995 level in each country – if the size, weight and acceleration of vehicles stay at 2000 levels. If not, those improvements in fuel economy will be mostly offset by shifts to larger, heavier, faster vehicles, as the first scenario shows.

In the second scenario, new car fuel consumption in 2010 is about 1.5 liter per 100 km lower in Germany and Denmark than in the United States. This reflects different starting points in each country, as well as

Figure 1.10

Scenarios of Fuel Economy Improvement for each Country

Figure 1.10a Denmark

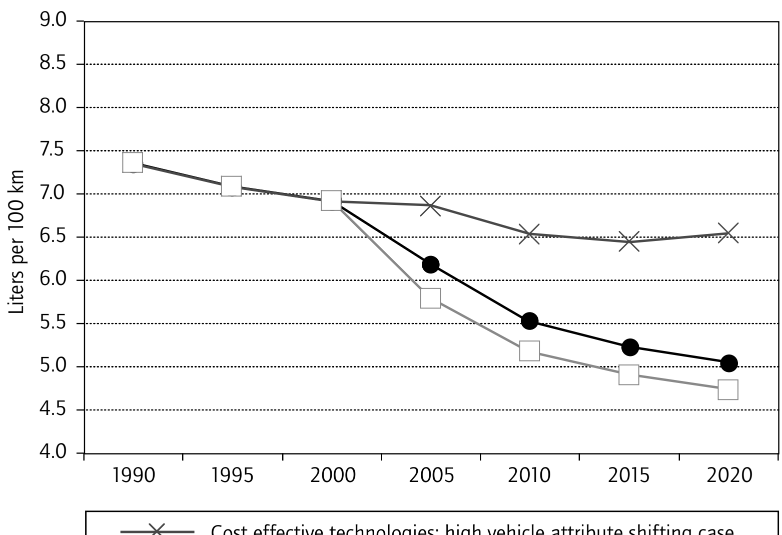


Figure 1.10b Germany

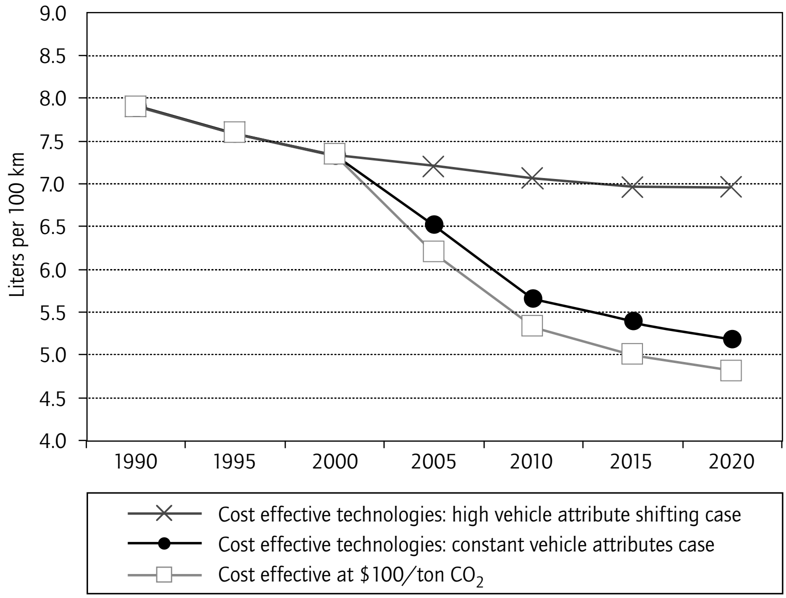
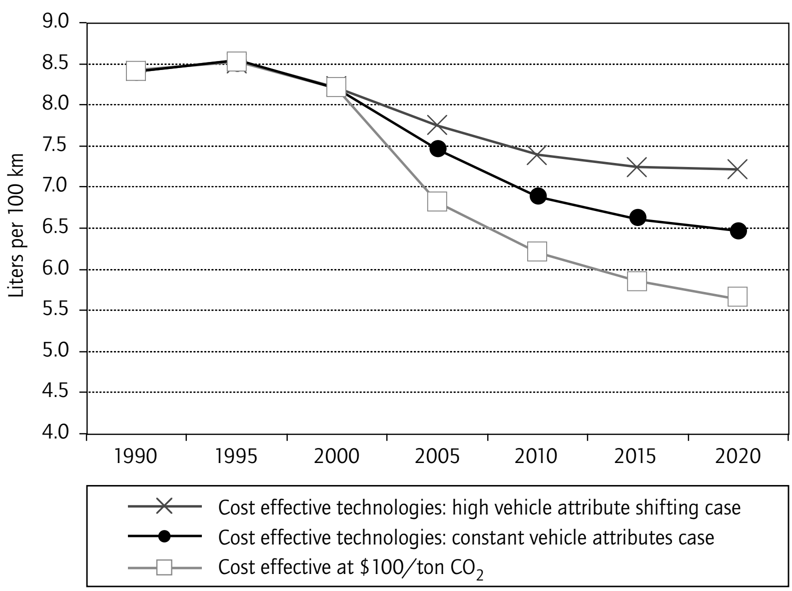


Figure 1.10c United States



different fuel prices, fuel and vehicle taxes, incomes, and average distance driven per vehicle, all of which affect the calculation of cost effective fuel economy levels. In addition, the first and second scenario for the United States are not as far apart as they are for Germany and Denmark because the US figure includes only cars. Although not shown in the figure, the United States analysis takes into account expected purchase shifting from cars to larger vehicles like minivans and sport-utility vehicles. The figures for Denmark and Germany also include some shifting to larger vehicles, and, in the first scenario, assume a combined market share for minivans and sport utility vehicles of around 15% in 2010.

The third scenario shows that for Germany and Denmark, fuel economy slightly above 5 liter per 100 km becomes cost-effective by 2010 at a CO_2 price of USD 100 per ton, reaching well under 5 liter per 100 km by 2020. In the United States, a CO_2 price of USD 100 per ton brings new car fuel economy to about 6 liter per 100 km by 2010 and to about 5.5 liter per 100 km by 2020.

Estimates of Fuel Use and CO_2 Emissions Through 2020

The scenarios for fuel economy in the three countries were used to develop similar scenarios for fuel use and CO_2 emissions (Figure 1.11). For this analysis, a model was used that tracks travel and average fuel consumption for vehicle stocks that takes into account stock turnover for each country[11].

The analysis shows that substantial, cost-effective reductions in fuel consumption and CO_2 emissions from light-duty vehicles are attainable by 2010 in all three countries. This is especially clear when comparing the three technology-penetration scenarios to a case where no

11. This model is documented in the online technical appendix. The key factors in using vehicle fuel intensity to calculate fleet emissions are the rate of stock turnover, reductions in on-road fuel economy and the rate of growth in vehicle travel. The approach also factors in the rebound effect, an increase in travel in response to lower costs per kilometer as fuel economy is improved. A –0.2 travel rebound elasticity is used for this calculation (i.e. a 10% reduction in fuel cost per kilometer yields a 2% increase in travel).

Figure 1.11

CO_2 Emissions Reduction Potential in Three Countries

Figure 1.11a Denmark

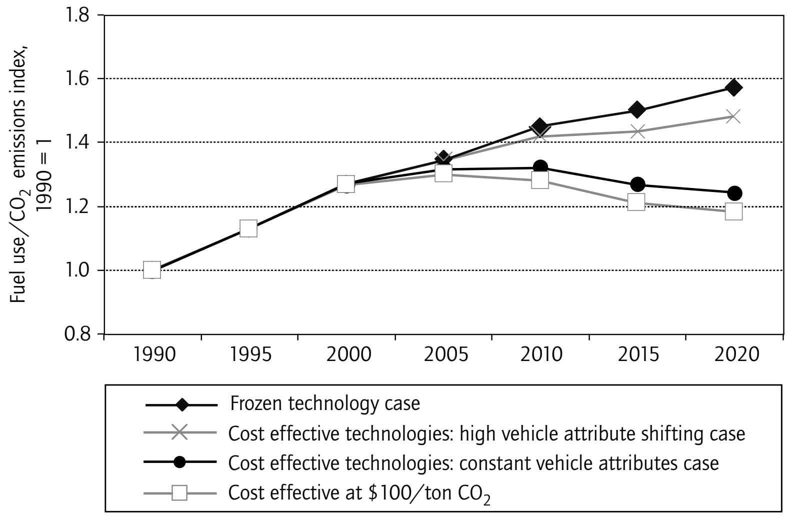


Figure 1.11b Germany

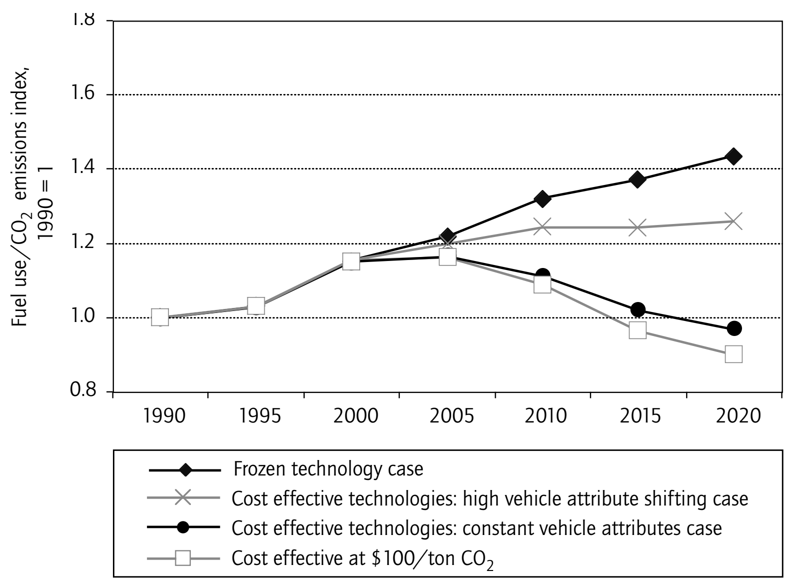
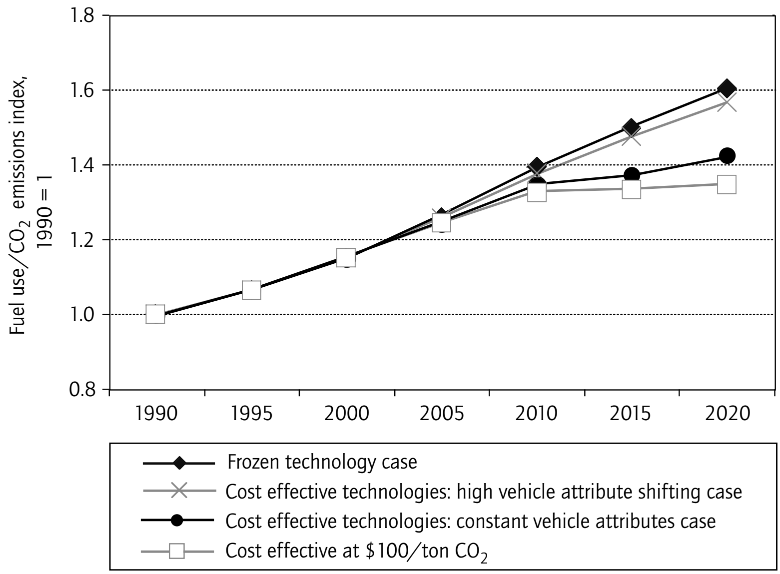


Figure 1.11c United States



technological improvements occur – the *frozen technology case*, for which fuel economy is held at 2000 levels. In this case, fuel use and CO_2 emissions grow roughly at the same rate as travel growth.

Given the high rate of growth in travel during the 1990s, and expected over the next decade, the use of cost-effective technologies can play an important role to save fuel and reduce light-duty vehicle CO_2 emissions. In Germany, given the relatively low expected travel growth rates, a return to 1990 CO_2 emission levels appears possible by 2010. Given the higher expected rates of travel growth for Denmark and the United States, such a large reduction does not appear likely. Nevertheless, in these countries, CO_2 emissions could decline 15%-20% by 2010, as the *constant vehicle attributes case* shows.

Yet the constant vehicle attributes case may be unrealistic without policies to contain the trend toward larger, more powerful vehicles. Half or more of the improvements in fuel economy from new technology could be forfeited to increases in vehicle size, weight, and horsepower.

Such shifts would translate into a similar loss in reductions of fuel use and CO_2 emissions. Thus efforts by producers to accommodate consumers by selling them ever larger, more powerful vehicles represent a key obstacle to maximizing the potential for reductions in CO_2 emissions through the improvement of fuel economy.

The Role of Diesels

The analysis has so far focused on gasoline vehicles and ignored the potential role of diesel engines. But recent advances have led to turbo-direct injection (TDI) diesel engines that use 10%-15% less fuel per kilometer than conventional diesel engines, and 25%-35% less than gasoline (non-direct injection) engines. Taking into account the energy content of the fuel and CO_2 emissions per joule, we calculate that TDI engines could emit 20%-25% less CO_2 per kilometer than gasoline vehicles. If they can overcome air-quality concerns and meet emissions requirements, TDI engines may play an important role in reducing CO_2 emissions reductions. In the US, this role will also depend on whether consumer interest in diesel vehicles increases, as it did in Europe during the 1990s.

Much of the per-vehicle benefit of diesels could, however, be lost to increased driving in response to lower diesel fuel costs due both to their better efficiency and often lower fuel prices. The rebound effect is particularly strong for diesels in countries where diesel fuel is much cheaper than gasoline. In Italy, for example, the average cost per kilometer for diesels is about half of that for similar gasoline vehicles. Assuming a –0.2 rebound elasticity, this lower fuel cost could result in a 10% increase in annual travel, which would erase much of the potential diesel fuel savings and CO_2 reductions per kilometer.

Diesels in 2000 represented about a quarter of all new cars sold in Western Europe, but a negligible percentage in the United States. Apart from losses due to the travel rebound effect, if TDI diesels reach 50% of light-duty vehicle sales by 2010 in both areas, average fuel consumption by new cars could fall 12%-15% in the United States and 7%-10% in Western Europe (taking into account that 25% of new cars there are already diesels). Similar benefits over the entire stock of vehicles could be achieved by 2020. The rebound effect, however, could reduce these benefits by up to half.

Improving Fuel Economy with Advanced Technology Propulsion Systems

This section discusses two promising vehicle technologies: gasoline/electric hybrids and fuel cell propulsion and drive train systems[12]. Hybrids made their initial commercial appearance in the late 1990s, first in Japan and then in United States, with sales scheduled to begin in Europe during 2001. Fuel-cell vehicles, still in the development and demonstration stage, are unlikely to be introduced commercially in light-duty vehicles before at least 2005. Below, we briefly describe these technologies, review their current status and estimate the cost of deploying them on light-duty vehicles. Finally, we develop two scenarios for future market penetration that projects their potential impacts on light-duty vehicle fuel use and CO_2 emissions, beyond that which may occur from fuel economy improvements using conventional technologies.

Gasoline/Electric Hybrid Vehicles

The term hybrid is a general term that embraces all vehicles with both an internal combustion engine (powered by gasoline, diesel or an alternative fuel) and an electric motor. If conventional vehicles and pure electric vehicles are at two ends of a spectrum, hybrid vehicles fall in between with any combination of engine and motor size, each combination involving different tradeoffs in cost, efficiency, and performance. Several years ago the major distinction was between series hybrids (where the engine and motor are aligned in a series

12. The discussion of hybrid and fuel cell vehicles and their characteristics is mainly based on a recent study conducted for the IEA by Energy and Environmental Analysis, Inc.

format, with the engine providing power to the motor, which provides power to the wheels) and parallel hybrids (where both the engine and motor provide power directly to the wheels). Most recent designs, however, have been parallel hybrids. The series hybrid, shown to be too expensive and less efficient than a well-designed parallel hybrid, has been largely abandoned.

Three different kinds of parallel hybrids, each with different levels of cost and fuel efficiency, have emerged. Hybrids can be classified according to the ratio of engine and motor power. The most fuel-efficient design (the 300-volt model) uses the electric motor for the steady driving load and the engine for peak load and battery recharge. However, this configuration is expensive, in part because it requires a large battery capacity. Thus, manufacturers are opting for less expensive designs with smaller batteries (the 42-volt models), which, however, forfeit some efficiency for lower cost. Table 1.1 shows plans for the introduction of hybrid models by manufacturers based on announcements made during 2000 and 2001.

Table 1.1

Hybrid Production Plans for Major Manufacturers

Hybrid	Manufacturer	US	Europe	Japan
300-volt	Toyota	2001	2001	1999
	Nissan	2002	2003	2001
	Ford	2003	2003	–
	Chrysler	2003	–	–
150-volt	Honda	2001	2001	2000
	Mitsubishi	2003	2003	2002
42-volt	GM	2004	2003	–
	Fiat	–	2003?	–
	Peugeot	–	2004?	–

For several reasons, the 42-volt systems, while not the most fuel-efficient, may become widespread. Most importantly, they provide more electrical power to the auxiliary systems of a vehicle than current batteries, which are usually 12-volt or 14-volt. Thus, they could allow the addition of features like four-wheel steering (especially to large sport utility vehicles), electric brakes, electric heat systems, and heat pump-based air conditioning – all of interest to manufacturers.

Table 1.2 estimates fuel economy for the three types of hybrids and conventional vehicles, and for the incremental costs of hybrids, that is, their costs over and above those of conventional vehicles, for current levels and in 2010[13]. Since some improvement is expected in fuel economy of conventional vehicles through 2010, the fuel economy benefit from hybrids decreases slightly over time. As the table shows, the estimated fuel economy for the three types of hybrids differs greatly; for the 150-volt it is 20% lower on the European cycle than

Table 1.2

Estimates for Fuel Economy and Cost of Different Hybrid Systems

Vehicle type	Fuel economy		Vehicle incremental retail price	
	Miles per gallon (US FTP cycle)	Liters/100 km (EU Test cycle)	Current low-volume production	2005-2010, high-volume production
Conventional vehicles				
Current base vehicle	26.5	9.6	Base	Base
2010 (BAU) vehicle	31.2	8.1	–	$ 370
Hybrid vehicles				
42-volt Hybrid	36.8	7.0	$ 800	$ 2 600
300-volt Hybrid	47.7	5.4	$ 7 400	$ 4 300

Source: EEA, 2000.

13. Detailed assumptions behind these estimates are available in the online technical appendix.

the 42-volt hybrid, but its incremental cost is more than three times higher. Costs, however, are projected to drop by 2010, as volumes increase and some learning benefits occur.

Fuel-cell Vehicles

Most major manufacturers are actively researching and testing different designs for light-duty fuel-cell vehicles. Simply put, fuel cells use hydrogen to generate electricity, which can be used to power a motor. Thus, a fuel-cell vehicle is much like an electric vehicle, only the power source is a fuel cell using hydrogen rather than a battery. Hydrogen can be stored directly on board the vehicle or obtained from the on-board reforming of another fuel such as methanol or gasoline. Fuel-cell vehicles with on-board hydrogen storage are essentially zero-emission vehicles, since the only product of fuel cell combustion is water.

Several manufacturers have announced the intention to market fuel-cell vehicles by 2005. However, given the enormous incremental costs of the fuel cell relative to the combustion engine, that goal will be a challenge. A number of technical issues have yet to be resolved, such as the best choice of hydrogen feedstock and where to produce hydrogen – whether on-board vehicles, at small reforming stations located at or near refueling sites, or at large central stations located farther from refueling sites.

There are two technological options for fuel-cell vehicles that operate on hydrogen. The first, the Proton Exchange Membrane (PEM) cell, works at room temperature. The PEM, which has been successfully demonstrated in prototypes, will most likely be the technology of choice for vehicles introduced by 2005. The second type is the solid oxide fuel cell which functions at elevated temperatures, that is, greater than 600°C. This type of fuel cell is being tested by a number of manufacturers but appears to be less technically mature than the PEM.

Both types of fuel cells run on hydrogen. The viability of hydrogen as a fuel, including its handling, distribution, and storage, is the subject of considerable debate. Therefore, reformers are being developed to produce hydrogen from methanol or gasoline on board vehicles. On-board reformers, however, are more costly and complex than storing externally-produced hydrogen in the vehicle, and they also reduce vehicle efficiency and produce some emissions, especially at cold start.

Table 1.3 estimates fuel economy and incremental costs for hydrogen, methanol and gasoline fuel cells. Since there are few available studies of the costs of fuel cells, these estimates are uncertain and

Table 1.3

Indicative Cost and Fuel Economy Estimates for Fuel-cell Vehicles

	Hydrogen	Methanol	Gasoline
Base vehicle weight (kg)	1 475	1 605	1 670
Power output (kW)	85	92	96
FC stack cost	$2 950	$3 100	$3 190
Fuel storage cost	$950	–	–
Buffer cost	–	$100	$100
Reformer cost	–	$1 840	$3 840
Motor cost	$2 850	$3 060	$3 180
Engine/transmission cost	($2 800)	($2 800)	($2 800)
Total variable cost	**$3 950**	**$5 300**	**$7 510**
Fixed cost amortization	$280	$330	$350
Incremental retail price at low volume production (20,000/yr)	$6 475	$8 635	$12 095
Incremental retail price at high volume production (200,000)	$4 100	$5 450	$7 600
Fuel economy (miles per gallon)	81	61	53
Fuel consumption (liters/100km)	2.9	3.9	4.4

Source: EEA, 2000.

preliminary[14]. The estimate of fuel economy for hydrogen fuel-cell vehicles (without reformers) excludes energy lost during the production and storage of hydrogen. These losses may reduce their net energy efficiency close to that of vehicles with on-board reformers.

Sales, Fuel Economy and CO_2 Scenarios for Advanced Technology Vehicles

Based on the projected cost and technical characteristics of hybrids and fuel-cell vehicles described above, the IEA constructed two projections that provide plausible scenarios of their market penetration in the United States through 2030 (Tables 1.4 and 1.5). While the scenarios are only for the United States, the results are broadly applicable to other countries.

The two scenarios, *Aggressive* and *Maximum* production increase, make different assumptions about the potential rates of increase in production and sales of hybrid and fuel-cell vehicles through 2030. The main limit to increases in production of advanced technology vehicles is the rate of product changeover – how quickly completely revised vehicle designs and new models are introduced. Since vehicle models typically remain on the market six to eight years before receiving a major overhaul or a redesign from the ground-up, in any five-year period about two-thirds of vehicle models are redesigned. But achieving even this rate of changeover to completely new engine technologies and drive-train systems would require huge investments and rapid increases in production capacity for necessary components and assembly plants. The aggressive scenario assumes that radical changes such as hybrids and fuel cells can be introduced at the point of product redesign about 33% of the time; the maximum scenario assumes a rate of 66%.

14. The few available studies of fuel cell costs are somewhat speculative about cost reductions that may result from learning and volume production to both the fuel cell systems themselves and from various components and systems. One major study, DTI (1999), estimates the cost of high-volume production of PEM fuel cells and other components associated with vehicular fuel cell systems (e.g., reformers and hydrogen storage). Based largely on the DTI estimates, the EEA, the source of these estimates, developed retail price-equivalent estimates for PEM fuel cells.

While going above 66% is certainly possible, it would pose a heavy investment burden on manufacturers.

The scenarios depicted here could be difficult and expensive to achieve if the costs of advanced technologies, especially for fuel cells, do not drop at least to within a few thousand US dollars of competing conventional vehicles. Consumers may tolerate some additional expense if the technologies offer some additional benefits like better air conditioning and heating systems. The primary point of this analysis, however, is not to develop rigorous sales forecasts, but simply to see how hypothetical increases in the numbers of advanced technology vehicles might affect fuel consumption and CO_2 emissions across the stock of light-duty vehicles.

Many of the assumptions behind individual numbers in the projections are noted in the tables. A few other points are made here. As of 2005, the analysis assumes that cost and fuel economy for hybrids are the averages of the 42-volt and 300-volt types. Those averages are close to the characteristics of 150-volt, reflecting an assumption that the typical hybrid of the future will be the 150-volt but that the other types may still be present on the market. Only two types of light-duty fuel cells are included in this scenario: gasoline (on-board reforming of hydrogen) and hydrogen (stored on board, supplied by reforming and refueling sites). We assume that gasoline fuel-cell vehicles will be the dominant commercial type until at least 2015, when enough off-vehicle hydrogen reforming capacity and vehicle refueling sites could be in place to support large-scale production of hydrogen fuel cell vehicles.

As the table shows, hybrids are already being marketed in the United States and appear to be off to a strong start. Three models of hybrid electric vehicle were sold in the United States in 2001 and were expected to have combined sales of close to 25 000. For both scenarios, we assume that large-scale commercial production of fuel cells will begin no sooner than 2008. In the maximum scenario, we project that manufacturers could introduce fuel-cell vehicles around 2005 in low-volume production for several years before large-scale operations begin. This time is needed to allow for continued research,

Table 1.4

Scenario 1: "Aggressive" Production Increase of Advanced Technology Vehicles for the United States

	Total annual production (000)	Share of total new LDVs	Notes
Hybrids			
2000	25	0%	Prius and Insight
2005	275	2%	10 models maximum, averaging below 30 000 vehicles per model;
2010	1 000	7%	Five-fold increase: 1-2 models in each class, 15-20 models, 50 000-75 000 production of each
2015	2 750	18%	20% share for cars, 15% for light trucks
2020	5 300	36%	40% share for cars, 30% for light trucks
2030	7 400	50%	50% share for cars and light trucks; growth slowed by emergence of fuel cells
Fuel Cells – Gasoline			
2005	5	0%	Limited commercial production, mainly for fleets (5 models, 1 000 each)
2010	50	0%	Expanded production for consumer markets
2015	500	3%	Ten-fold growth in commercial production to 500 000
2020	500	3%	Shift to hydrogen fuel cells underway
2030	0	0%	Shift to hydrogen fuel cells completed
Fuel Cells – Hydrogen			
2005	0	0%	No commercial production of light-duty vehicle hydrogen fuel cells; most applications for buses
2010	12	0%	Very limited commercial production, mainly for fleets (5 models, 2 500 each)
2015	50	0%	Focused sales in a few markets with hydrogen infrastructure development
2020	500	3%	Infrastructure becomes widespread
2030	5 900	40%	Becoming the dominant vehicle type sold
Combined Share of Gasoline and Hydrogen Fuel Cells			
2005	5	0%	
2010	58	0%	
2015	550	4%	
2020	1 000	7%	Between 2020 and 2030, a 33% changeover rate from
2030	5 900	40%	conventional and hybrid to fuel cell
Total Share of Hybrids plus Fuel Cells			
2005	280	2%	
2010	1 058	7%	
2015	3 300	22%	
2020	6 300	42%	
2030	13 300	91%	

Table 1.5

Scenario 2: "Maximum" Production Increase of Advanced Technology Vehicles for the United States

	Total annual production (000)	Share of total new LDVs	Notes
Hybrids			
2000	25	0%	Prius and Insight
2005	275	2%	10 models maximum, averaging below 30 000 vehicles per model;
2010	3 000	20%	Starting in 2007, all new models are hybrids or fuel cell.
2015	6 000	40%	
2020	9 900	66%	Hybrid sales reach their maximum
2030	1 000	7%	Sales decline with the increase in sales of fuel cells
Fuel Cells – Gasoline			
2005	10	0%	Initial commercial production (5 models, 2 000 each)
2010	500	3%	Expanded production of fuel cells for consumer markets; ten models at 50 000 each
2015	2 000	13%	Reaches 20 models at 100 000 each
2020	500	3%	Shift to hydrogen fuel cells underway
2030	0	0%	Shift to hydrogen fuel cells completed
Fuel Cells – Hydrogen			
2005	5	0%	Limited commercial production, mainly for fleets (5 models, 1 000 each)
2010	50	0%	Focused sales in a few markets with hydrogen infrastructure development
2015	500	3%	Infrastructure becomes widespread, sales increase tenfold
2020	3 700	25%	Becoming dominant vehicle type sold
2030	13 200	90%	Dominant vehicle type sold
Combined Share of Gasoline and Hydrogen Fuel Cells			
2005	18	0%	
2010	550	4%	
2015	2 500	17%	
2020	4 200	28%	Between 2020 and 2030, a 66% change over rate from
2030	13 200	90%	conventional and hybrid to fuel cell
Total Share of Hybrids plus Fuel Cells			
2005	293	2%	
2010	3 550	24%	
2015	8 500	57%	
2020	14 100	95%	
2030	14 200	97%	

development, and demonstration to improve performance and reduce costs to near-competitive levels.

The *aggressive scenario* assumes about one-third of all redesigned models introduced after 2010 will be either hybrid or fuel cell. Hybrids dominate the introduction of new advanced technology models between 2010 and 2020, when they gradually give way to fuel-cell vehicles. Starting in 2020, fuel cells begin to be produced on a large scale; by 2030, they displace most remaining conventional vehicles and most hybrids as well. This scenario projects that combined sales of hybrid and fuel-cell vehicles will reach about 22% by 2015 and 91% by 2030.

In the maximum scenario, hybrids dominate advanced technology introductions from 2005 to 2020, but are then overtaken by fuel cells, which reach 90% of total light-duty vehicle sales by 2030. It is assumed that about 66% of all new models introduced after 2010 will be powered by a hybrid or fuel-cell system. Therefore, large-volume sales of the advanced technologies would begin earlier than in the aggressive scenario – with sales reaching 24% in 2010 (nearly all of which hybrids), over 50% by 2015 and over 90% by 2020. This ambitious growth path reflects what could happen if both technologies are so successful that by 2010 most manufacturers are committed to changing over to them in the majority of their model lines. This, in turn, could occur from a strong policy push to encourage adoption of these technologies.

Fuel Economy and CO_2 Scenarios

Table 1.6 shows IEA's estimates of fuel economy and reductions in CO_2 emissions per kilometer for new hybrids and fuel-cell vehicles, compared to new conventional vehicles in the same year, out to 2030[15]. Based on these estimates and the production scenarios, and using the forecasting tool described above and in the on-line appendix, scenarios

15. These estimates use the EEA data discussed above and are based on the foregoing discussion of the likely attributes of the two new technologies. Note that for 2005, we project a higher level of improvement is projected, based on the assumption that hybrids and fuel cell vehicles will be introduced with other fuel-saving technologies (e.g., low rolling resistance tires and weight reduction).

Table 1.6

Characteristics of Hybrid and Fuel cell Vehicles Used in Scenarios

	Percentage reduction hybrid/fuel cell vs. new conventional vehicles		Notes
	Fuel use (gasoline equivalent)	CO_2	
Hybrids			
2005	25%	25%	Fuel economy based on conventional vehicle estimate for 2005, EEA's estimates for 150-volt hybrid in 2010
2010	21%	21%	Conventional vehicles are expected to continue improving, thus reducing the benefit of hybrids over time
2015	21%	21%	
2020	21%	21%	
2030	21%	21%	
Fuel cells – gasoline			
2005	42%	42%	
2010	39%	39%	EEA's estimates for fuel economy increment for gasoline fuel cell in 2010
2015	39%	39%	
2020	39%	39%	
2030	39%	39%	
Fuel cells – hydrogen			
2005	62%	62%	Assume CO_2 is similar to fuel economy change until hydrogen is produced renewably beginning in 2020
2010	60%	60%	Fuel economy difference in 2010 from EEA, price differential from EEA
2015	60%	60%	
2020	60%	65%	Assume that 10% of hydrogen is renewable, provides 80% reduction in CO_2/km
2030	60%	69%	25% of hydrogen is renewable

were developed for stock fuel economy, fuel use, and CO_2 emissions resulting from the introduction of the hybrid and fuel-cell technologies in the United States through 2030 (Figures 1.12 and 1.13). For comparison, it includes the scenarios presented earlier for the US (Figures 1.10 and 1.11) that show the effects of the introduction of conventional vehicle technologies, and extends them through 2030.

The CO_2 estimates presented reflect full fuel cycle considerations, including upstream fuel extraction, conversion, and distribution processes. To do this, the following assumptions were made:

- For gasoline vehicles, CO_2 emissions are a direct function of vehicle fuel economy; that is, all upstream processes are the same per liter of fuel supplied for all gasoline vehicles, regardless of vehicle technology.

Figure 1.12

US New Car Fuel Economy under *Cost Effective* and *Advanced Technology* Cases through 2030 (Liters/100 km)

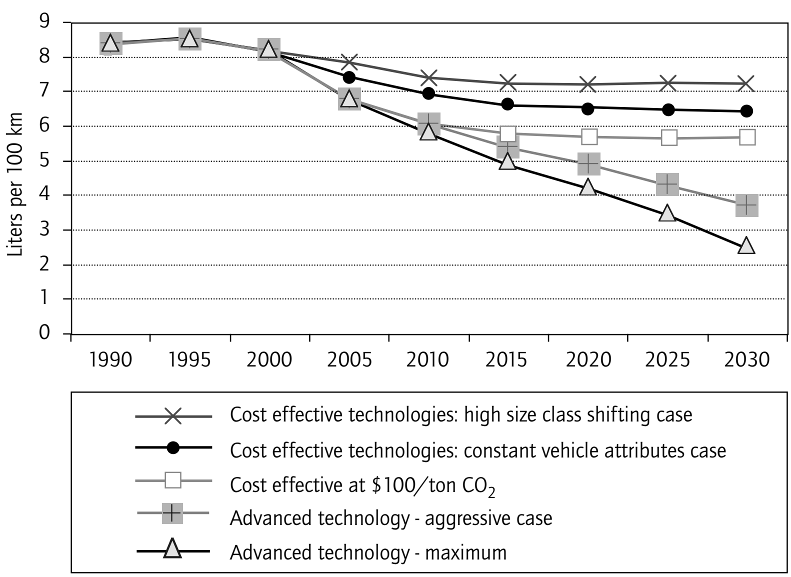
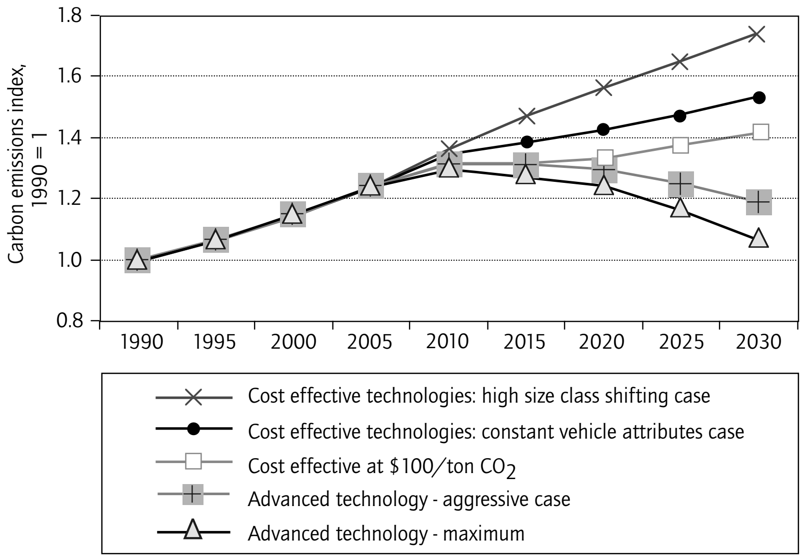


Figure 1.13

US Light-Duty Vehicle CO_2 Emissions under *Cost Effective* and *Advanced Technology* Cases through 2030



- For hydrogen fuel cells, upstream CO_2 emissions from the production of hydrogen are equal to those for providing gasoline on a per-unit energy basis[16]. Only to the extent that hydrogen fuel cells are more efficient than gasoline ones do they produce fewer upstream emissions.
- Hydrogen fuel-cell vehicles are much more efficient, and therefore offer reductions in greenhouse-gas emissions relative to gasoline

16. Actual upstream CO_2 (and other greenhouse gas) emissions during hydrogen production are heavily dependent on the method used to generate hydrogen. For example, hydrogen derived from electrolysis will release upstream emissions as a function of the type and amount of fossil fuel used to generate the electricity. These emissions can vary from near zero (e.g., for electricity from nuclear or renewables) to well above the level required to produce an energy equivalent amount of gasoline (e.g., for electricity from coal plants). In order to keep the results of the analysis broadly applicable, a simplifying assumption is used.

fuel cells. After 2020, renewable and/or nuclear power will increasingly be used to generate electricity that is in turn used to produce hydrogen, lowering upstream emissions.

Under both the aggressive and maximum scenarios for the US, the year 2015 appears to be a turning point, as improvements in fuel economy from advanced technologies begin to yield outright reductions in CO_2 emissions from light-duty vehicles. Under the maximum scenario, emissions by 2030 have been reduced almost to 1990 levels and are heading lower. Both scenarios take into account a travel rebound effect from lower fuel costs.

Taking into account both the cost effective technology scenarios from the previous section and the advanced technology scenarios presented here for the US, substantial fuel savings and CO_2 reductions appear possible by 2020. With vehicle attributes such as size, weight and acceleration held at their 2000 levels, and aggressive adoption of advanced propulsion technologies such as hybrid-electric and fuel-cell systems, new light-duty vehicle fuel consumption could be cut by up to 40% in 2020, and over 50% by 2030. Fuel economy for the existing stock of light-duty vehicles would improve more slowly, as it is replenished by the new, higher efficiency models. By 2020, fuel consumption and CO_2 emissions of the total stock could be cut by up to 30%, and by more than 40% by 2030. Greater use of diesels could contribute another 5%-15% reduction in fuel use, especially in North America where the current diesel market share is quite low.

Measures to Promote Efficient Technology for Light-Duty Vehicles

IEA's analysis of Germany, Denmark and the United States shows that existing technology has great potential for improving fuel economy and therefore cutting greenhouse gas emissions. Conventional technologies could improve fuel economy (i.e. reduce fuel consumption) by as much as 25% by 2010, cost-effectively and at current fuel prices (see Figure 1.13).

Both these and next generation technologies such as gasoline/electric hybrid and fuel-cell systems could yield substantial greenhouse gas reductions in the Kyoto timeframe and beyond. However, none of these technologies appears likely to be deployed to their its fuel saving and CO_2 reduction potential without policy intervention.

During the past ten years, many new technologies have been deployed on light-duty vehicles, at rates of adoption not much different from those projected in the future in IEA's cost-effective technology cases. But manufacturers have not used the technology primarily for saving fuel or for reducing greenhouse gases, but to improve other vehicle attributes that consumers consider important, such as increased vehicle size, weight, and power. In this way, the fuel economy of new vehicles in both Europe and North America did not improve during the 1990s. New vehicles on both continents have grown larger and more powerful. Consumers in North America have shifted from buying cars to light trucks (vans, sport-utility vehicles, and small pickups), a trend that could also spread to Europe. The challenge for policymakers then, is to encourage the use of technology for improving fuel economy rather than for improving other attributes of vehicles. Policy should be directed to moving markets towards maximizing the benefit of these cost-effective options to improve fuel economy and thus save fuel and reduce CO_2 emissions.

Next-generation technologies reduce energy use and emissions per vehicle to such a large extent that there is little risk in completely losing these public benefits to private consumer interests. However, any advanced technology faces high costs due to a lack of production capacity and production experience, and manufacturers' unwillingness to invest due to concerns about consumer acceptance and sales. Policies will also be needed to overcome these obstacles.

The Role of Consumer Interest

While consumers care about fuel costs, their interest in purchasing vehicles with fuel economy higher than that of their current vehicles appears to be limited, especially if they must trade off other attributes like horsepower, size and weight. As incomes increase, consumers appear to be re more concerned about safety and vehicle amenities and less concerned about costs. Even in countries with relatively high fuel prices, such as Denmark and Germany, the savings from switching to a vehicle with higher fuel economy may not be enough to encourage most drivers to make a switch to a smaller or less powerful car. For example, for a German or Danish driver who pays around USD 1 per liter of gasoline and who drives 20 000 km a year, the fuel savings from switching from a typical large car (with fuel consumption of about 10 liters per 100 km) to a compact car (about 7 liters per 100 km) would be about USD 600 per year. Many consumers appear to be unwilling to trade the comfort, safety and power of a larger vehicle for such savings. If they continue to value other vehicle attributes more highly than fuel savings, new technologies will likely be applied in that direction.

Another reason for consumers' disinterest may be lack of knowledge. Even within the same size class of vehicle, consumers could enjoy large fuel savings if they purchase those vehicles with the best fuel economy, as Table 1.7 shows. Many consumers may not realize the fuel savings potential from shifting between similar size vehicles. In some cases, they may be unwilling to pay more up front for more efficient but more expensive vehicles, for the sake of fuel cost savings in the future. Or they may perceive other disbenefits from switching, such as slower acceleration. But probably most are simply unaware of their options. If consumers are unaware of fuel economy differences among vehicles, manufacturers will have little incentive to make fuel economy improvements.

Policy Options for Promoting Near-Term Technologies

If better vehicle fuel economy is to provide a significant near-term contribution to saving oil and reducing CO_2 emissions, better signals are needed to encourage producers and consumers to pay more attention to fuel economy. Polices are needed that:

- Encourage manufacturers to use available technologies to improve fuel economy rather than hold it constant while increasing vehicle size, weight, and power.

Table 1.7

Best and Worst European Fuel Intensities by Market Class (model year 2000)

	Vehicle fuel consumption, European city/highway test cycle (liters per 100 km)			Percent difference	
	Best diesel	Best gasoline	Worst *	Worst v. best diesel	Worst v. best gasoline
Mini / Subcompact	4.4	5.8	9.6	118.1%	65.5%
Compact	5	7	11.1	122.0%	58.6%
Midsize	5.2	7.4	12.1	132.7%	63.5%
Large	6.6	8.8	13.6	106.1%	54.5%
Minivan	6.6	10	13.3	101.5%	33.0%
SUV**	7.8	8.6	16.6	112.8%	93.0%

** Excluding "super luxury" and "super high performance" cars.*
*** SUV = sport-utility vehicle.*

- Sharpen the distinctions between more efficient and less efficient vehicles to affect consumer choice at time of purchase.
- Encourage manufacturers to deploy advanced technology vehicles by reducing investment risks and encourage consumers to purchase them by reducing initial costs.

A number of policy options for promoting near-term technologies could meet the first and second objectives: these mainly fall in the areas of fuel pricing and vehicle taxes, rebates and standards.

Fuel Pricing

Fuel pricing sends a signal to consumers about both vehicle choice and level of travel. The relatively high fuel prices in European countries have probably been an important factor in fuel intensity, vehicle size, and driving levels, which are lower than in the United States. However, even big changes to fuel prices may not have much additional impact on vehicle choices. For example, for an average Danish or German driver, an increase in fuel prices of USD 0.25 per liter raises annual fuel costs by USD 150. In the United States, with its much lower fuel prices, the effect of a large price increase (nearly USD 1 per gallon) would be USD 200-USD 300 a year. Given the increasing political difficulty of raising fuel taxes in many countries, it is useful to explore alternatives to modifying the price signal to vehicle buyers.

Vehicle Taxes, Feebates and Standards

A policy-pricing tool that could be used to emphasize fuel consumption differences among new vehicles is the feebate. In this context, a feebate refers to fees or rebates applied to the purchase price (or registration fee) of a vehicle. The levels of the fees and rebates are determined by specific attributes of each vehicle model, such as rated fuel consumption per 100 km. One appealing feature of a feebate system is that it can be revenue neutral, with fees on high consumption cars offset by rebates for cars with low consumption. A feebate system based on rated fuel economy or fuel intensity can differentiate vehicle prices while leaving the average price of a new vehicle, and the overall tax burden on consumers, unchanged. For example, a modest feebate, of USD 250 in fee or rebate for each liter per 100 km reduction in fuel consumption, could provide a signal to consumers as strong as a USD 0.25 per liter increase in fuel taxes[17].

In place of the feebate system, countries with high taxes on vehicle purchases (such as Germany, which has a valued-added tax of 16% amounting to an average of about USD 2 500 per vehicle), could convert their current taxes to those based on fuel consumption. For the average new car (with fuel economy of 8 liters per 100 km), a fee of USD 300 per liter per 100 km would amount USD 2 400 per vehicle, about the same

17. A 250 USD fee per liter per 100 km increase in rated fuel consumption is equal to the additional fuel cost over 100 000 km of driving from a 0.25 USD tax increase.

as the current average. Of course, if manufacturers improved fuel economy to qualify for the lower fee and consumers bought more efficient vehicles, the average fee and revenue would drop through time unless the tax rate were raised. Denmark could introduce very aggressive fuel consumption-based taxes – more than USD 1 000 per liter per 100 km – and preserve its current average vehicle tax, since its current average tax is more than USD 20 000 per vehicle. In fact Denmark has begun to move in this direction (see box). In the United States, with no federal tax on vehicles, a revenue-neutral feebate may be more appropriate.

Since Denmark has a relatively small market for new cars, its tax policy mainly affects the choices made by consumers from a mix of vehicle models marketed by foreign manufacturers. In Germany, with its larger vehicle market and major vehicle manufacturing industry, a feebate could encourage consumers to shift to more efficient vehicles *and* encourage manufacturers to direct technological improvements toward reducing fuel consumption. This signal to manufacturers would be simple and clear. If reducing the rated fuel consumption of a vehicle by 1 liter per 100 km lowers the fee by USD 500, then producers have a direct incentive to add technology or otherwise take steps costing up to USD 500 to achieve such a reduction, since the cost would be more than offset by a reduction in the fee, and thus in the vehicle's after-tax price. But it is unclear whether Germany's market is large enough to prompt manufacturers to make major investments, especially for models also sold in other markets, which may not have a similar system of fees and rebates.

With the largest new car market in the world, about 15 million new cars and light trucks sold each year, the United States is in the best position to affect manufacturer behavior. The imposition of a fee or feebate system based on fuel consumption would spur manufacturers worldwide to reduce the fuel intensity of the vehicles they produce, as each liter per 100 km reduction in fuel use would translate into a known, quantified change in the tax or rebate of their vehicles sold in the United States.

The existing fuel economy program in the United States is based primarily on the Corporate Average Fuel Economy (CAFE) standards.

Fuel Consumption-based Vehicle Taxes in Denmark

Some countries such as Denmark are already moving towards fuel consumption-based fees and feebates. In 1997 Denmark introduced such a fee in addition to its existing value-added tax applied at registration (Table 1.8). This fuel consumption fee can add up to USD 1 921 to the cost of a new vehicle for high fuel consumption cars. (In Denmark, however, few passenger vehicles are rated above 10 liters per 100 km, at which level the tax is USD 675 per vehicle). Although this tax is high, the difference among vehicles is not great, less than USD 400 in incremental tax for a vehicle with 3 liters per 100 km above the average of 7 liters per 100 km. This difference seems small compared to a first-time registration fee of more than USD 22 000 for an average vehicle. If more of the Danish value-added tax were converted to a fuel consumption-based fee at a level that preserves current revenues, the difference in fees between vehicles with different fuel economy levels could be much greater, and send a stronger signal to consumers to choose vehicles with high fuel economy, without increasing the average tax rate or total tax burden.

In December 1999, the Danish Government took another step towards a more fuel consumption-based vehicle tax system – by adding a rebate component to its fuel consumption tax. It instituted a rebate on the value-added tax for very efficient vehicles – gasoline vehicles with fuel consumption below 4 liters per 100 km and diesels below 3.5 liters per 100 km. The rebates are generous; for gasoline vehicles with fuel consumption rated between 2.5-3 liters per 100 km, they reduce the value-added tax by half. As the average value-added tax is around USD 22 000, this represents a large saving for qualifying vehicles. However, as of model year 2000, no major brand name gasoline or diesel cars were available in Denmark with fuel consumption rating low enough to qualify for a rebate. If manufacturers respond to this policy by marketing vehicles with fuel consumption that merits a rebate, or if it is expanded to cover vehicles with higher levels of fuel consumption, purchases of more fuel-efficient cars could increase substantially and fuel consumption could decline sharply in Denmark.

Table 1.8

Schedule for Vehicle Fuel Consumption Tax for Vehicles Registered after 1 July 1997

Vehicle fuel consumption category (liters per 100 km)	Tax rate	
	Danish Kronor (Dkr)	US dollars (at PPP)*
5	0	0
6	1 740	$ 208
7	2 620	$ 313
8	3 480	$ 415
9	4 360	$ 520
10	5 660	$ 675
15	10 000	$1 193
20	14 360	$1 714
>22	16 100	$1 921

* *On average in 1998, DKK 8.58 = USD 1.00 on a PPP (purchasing power parity) basis.*

These standards yielded, or at least coincided with, a near doubling of fuel economy between 1977 and 1986. The standard, however, has not changed significantly in more than ten years and neither has fuel economy for new cars or light trucks. A new report by the US National Research Council (NRC 2001) points out a number of significant shortfalls in the current system. It proposes steps that would effectively move the system closer to one with the benefits offered by a feebate system, mainly by adding incentives for manufacturers to take actions at the lowest marginal cost (through adding credit trading removing elements that cause distortions). As an alternative to revising the current CAFE law, a feebate system could be added to complement the current CAFE standards. Feebates would encourage manufacturers to improve fuel economy while the standards would continue to provide a lower boundary for the average fuel economy of each manufacturer's vehicles.

The United States already has a fuel economy-based fee on vehicles – the *gas guzzler tax* – but it is limited to a few car models of very low fuel economy. The tax applies only to cars with a rated fuel economy below 22.5 miles per gallon (above 10.5 liters per 100 km). Since 1990, the fee has been set at USD 1 000 per vehicle for cars just under 22.5 MPG, increasing to a maximum fee of USD 7 700 for vehicles with less than 12.5 miles per gallon (above 18.8 liters per 100 km). Over the past 20 years, the tax has dramatically affected the sales and fuel economy of vehicles subject to it. For example, several models of Lincoln and Cadillac subject to the tax in the early 1990s have improved their fuel economy and are now exempt. Total revenue under the program has fallen from USD 144 million in 1992 to USD 48 million in 1997, as manufacturers improved the fuel economy of vehicles in order to reduce or avoid the tax. There are now very few vehicles subject to this tax.

This *guzzler* tax could be broadened to cover light trucks and more cars (by raising the miles per gallon limit). A rebate also could be added, perhaps for very fuel-efficient vehicles. The Bush administration's proposed purchase incentives for advanced technology vehicles, discussed below, would work like such a rebate. An incentive for very fuel-efficient vehicles could be designed to bring the current *guzzler* tax system into revenue neutrality, which would probably increase its political and public acceptance.

The measures encouraging vehicle efficiency in the three countries are quite varied, with the United States relying primarily on a regulatory approach (CAFE), Germany on fuel taxes, and Denmark on a combination of fuel taxes and very high vehicle registration fees. All three countries could improve their policies by moving towards a fuel consumption-oriented fee or feebate. This could be accomplished without disrupting overall revenue from vehicle taxes.

Policy Options for Realizing the Potential of Next Generation Technologies

As discussed above, a number of advanced vehicle technologies are emerging with the potential to dramatically reduce light-duty vehicle fuel consumption and greenhouse-gas emissions. Promising technologies such as direct-injection diesel engines and hybrid gasoline/electric vehicles are already finding their way onto the market. Fuel cell technology is at a crucial stage where, if provided with policy support, commercial introduction could be only a few years away. The success of these and other advanced technologies depends on their cost, performance and reliability. Ongoing research, development, and demonstration are important to their evolution. But the key to commercializing promising technologies in the near term will be overcoming market barriers common to many new technologies. Policies that encourage manufacturers to invest in innovative technologies and consumers to purchase them would help overcome these barriers.

Several different kinds of policies could accelerate the commercial introduction of advanced technologies. These include price incentives to encourage purchases of vehicles that employ advanced technologies, performance-based sales requirements for vehicles that achieve specific fuel consumption or CO_2 emission reduction targets, and a combination of the two. While these approaches have at least been considered in many different countries, few countries have yet adopted them with the purpose of encouraging the introduction of next generation fuel-economy technologies.

Price Incentives

Since 1998, Japan has been offering price incentives of about USD 3 500 per vehicle for hybrid gasoline/electric vehicles. It is the first country to manufacture and sell significant numbers of these advanced technology vehicles with sales of nearly 50 000 hybrids from model year 1998 through 2000. While the precise effect of these next-generation technology incentives on hybrid sales in Japan is unclear, they have made the first hybrids competitive with conventional vehicles.

Several similar proposals have been put forward in the United States, including a new proposal that is part of the Bush administration's recent energy plan. Several bills have been introduced in the 2001

Congress that include hybrid vehicle and fuel cell incentives. These proposals typically include requirements that vehicles contain specific technologies (such as motors, hybrid systems or fuel-cell systems) and achieve a certain minimum level of fuel economy, in order to qualify for tax breaks. In some cases the proposals include a system of graduated tax breaks that increase in proportion to improvements in vehicle fuel economy.

These approaches show how price incentives can create a market pull for advanced technology vehicles by bringing their purchase price closer to, or even below, comparable vehicles with conventional technology. The policies target consumers who are willing to try something new and different in return for a financial payoff. But price incentives may do little to spur sales until the cost of vehicles possessing the target technology falls into a commercially competitive range. Indeed, a retail price advantage may be necessary for advanced technology vehicles to overcome perceived shortfalls in performance and a general consumer aversion to purchasing new technology vehicles. Whether price incentives can be used successfully to foster sales of these technologies, especially fuel cells, over the next few years remains to be seen. Nevertheless, any incentive system that removes the hurdle of higher initial cost at least provides new technologies with a fighting chance of being successful.

Performance-based Sales Requirements

Incentives could focus on encouraging manufacturers to use advanced technologies as part of a larger effort to meet targets for the reduction of CO_2 emissions. For example, the State of California in the United States, as part of its Low Emission Vehicle program, will require 10% of vehicles to be sold at zero (or very near zero) emissions beginning in 2003 (although some averaging with sales of slightly higher-emission vehicles will be allowed). Only if they meet the specified sales targets for very low-emission vehicles will manufacturers be permitted to continue to sell conventional vehicles. The only vehicles that currently meet the near-zero criterion are electric and fuel-cell vehicles. Thus, this incentive represents a combination of a performance-based requirement and the promotion of specific next-generation technologies.

A similar approach could target either fuel consumption or CO_2 emissions. An ambitious threshold (i.e. low fuel consumption or CO_2 emissions per kilometer) could be set below which vehicles would qualify. Manufacturers could be required to sell a minimum number of qualifying vehicles per year in order to be allowed to sell other vehicles in the same market. Manufacturers would be free to determine how to meet the sales quota, whether through internal subsidies, fleet sales, aggressive marketing, etc.

Applying such an ambitious policy in a relatively small country like Denmark poses problems. If Denmark adopts a very strict requirement, certain manufacturers might decide to stop selling vehicles there rather than comply, if they perceive that compliance is more expensive. Such a program is less risky in countries such as Germany, which has a much bigger market and its own vehicle manufacturing industry. Manufacturers developing vehicles with low CO_2 emissions for the German market would probably sell enough vehicles to cover most or all of the investment costs. Sales of new light-duty vehicles in California are about 1.5 million per year, near the midpoint between the nearly 4 million sold in Germany and the 150 000 in Denmark.

Combined Incentive/Requirement Approach

The price incentive and sales requirement approaches could be combined; a country could offer price incentives to consumers directed toward the purchase of advanced technology vehicles and simultaneously require manufacturers to sell a minimum number of such vehicles.

Combined incentives could help to bring next generation technologies to market, even in a smaller country like Denmark. For example, if a combined incentive/requirement program in Denmark were successful in spurring sales of 7 500 qualifying vehicles (5% of Danish new vehicle sales), that could be enough to prompt automakers in other countries to invest in production facilities with the intention of selling a large percentage of early production runs in Denmark. If Denmark teamed up with other countries in such a policy initiative, it could result in a much larger *guaranteed* market. Demand for 20 000 vehicles of a particular model could be sufficient to allow a manufacturer achieve significant economies of scale for the production of key advanced technologies and components such as drive trains, motors, and battery systems[18]. By diverting less than 1% of its annual sales of new light-duty vehicles toward the purchase of advanced technology vehicles, Germany or the United States could create a demand for 20 000 such vehicles.

Achieving Success with the EU/ACEA Voluntary Agreement

Do European countries such as Denmark and Germany really need any additional policies to promote fuel-efficient vehicles? A voluntary agreement between the European Union and the Association of European Car Manufacturers (ACEA) is already in place to reduce average CO_2 emissions of new cars by 25% in 2008 from 1995 levels[19]. In terms of fuel consumption, this translates into a change from about 7.6 to 5.7 liters per 100 km for the current mix of fuels. If this voluntary agreement succeeds, it would likely be among the most important CO_2 reduction strategies implemented by European Union countries. However, the goals of the agreement are challenging. There is no guarantee that the ACEA will be able to meet them, especially since the agreement could be annulled if certain conditions are not met. These conditions include the availability of fuels that enable use of direct injection technologies (low sulfur gasoline and diesel fuel), prevention by the European Commission of *distortions of competition* that might disadvantage European manufacturers trying to meet the

18. As estimated by Energy and Environmental Analysis, 1999, "Canadian Transportation Study #3: Road Vehicle and Fuels Technology Measures Analysis", prepared for the Canadian Transportation Issue Table, Public Works and Government Services Canada, Science Directorate Informatics and Professional Services Sector, Hull, Quebec, Canada.

19. Similar agreements have also been developed between the EU and the Japanese and Korean auto manufacturers selling cars in Europe.

CO_2 targets, and the *unhampered diffusion* of fuel-efficient technologies onto the market. A clear focus of concern is ACEA's ability to use direct injection technologies to help it meet the target.

Based on the analysis presented above, a 25% reduction in CO_2 emissions from light-duty vehicle fuel economy improvement appears to be technically achievable, and even inexpensive, using currently available cost-effective technologies. But this includes the use of direct injection technologies, which could be at risk in the future as emissions standards tighten. On the other hand, the emergence of hybrid vehicles may make it possible for manufacturers to reach a 25% CO_2 reduction goal even without direct injection, but most likely at a higher overall cost.

But IEA's estimate that a 25% improvement in fuel economy is achievable with available technology is dependent on the assumption that vehicle attributes such as size, weight and power do not change significantly over the next 10 years. If manufacturers yield to the trend toward larger, heavier and more powerful vehicles, they will not benefit from the full potential for emissions reductions from new technologies and may have much more trouble meeting the EU target.

For this reason, policies that support the ACEA in reaching the target are clearly desirable. The challenges posed by enabling fuels, the diffusion of CO_2-efficient technologies and the trend toward larger, more powerful vehicles suggests that governments have an important role in ensuring the success of the EU/ACEA agreement. Individual countries could complement the agreement by promoting fuel-efficient technologies and vehicles through price and performance incentives, for near-term and next generation technologies.

Policy Example: Maximizing Near-term Fuel Economy Benefits of Cost-effective Technologies

Cost-effective technologies exist to reduce fuel consumption per kilometer in new cars and light trucks by up to 25% by 2010 in Denmark, Germany and the United States. Assuming this is true for all IEA countries, the main concern for policy makers is to ensure that these potential benefits are not lost to future increases in average vehicle size, weight and power. This policy example involves the conversion of existing vehicle sales and/or registration taxes to a system based at least in part on fuel economy, or, for those countries without broad national vehicle taxes, such as the United States, a revenue-neutral feebate to encourage the purchase of high-fuel economy vehicles. (An analysis of the level of tax needed to avoid loss of fuel economy to purchase shifts is beyond the scope of this publication, and in any event would be the task of each government to assess, taking into account the singularities of its market.)

If a country creates a tax or feebate system based on fuel consumption that successfully maintains vehicle attributes such as size, weight and power at their 2000 levels, new light-duty vehicle fuel economy would improve by up to 25% by 2010. Without such policies, half or more of this potential gain could be lost to larger, heavier, and more powerful vehicles. Thus, the policy would improve fuel economy anywhere from 10%-25% more than if no action is taken, depending on how much change occurs in the absence of the policy. By 2010, the average fuel economy improvement of the entire light-duty vehicle stock would be in the range of 5%-15%, given the slow rate of vehicle turnover. After taking into account a travel rebound effect (using a –0.2 elasticity of travel with respect to fuel costs), oil consumption and emissions of CO_2 would fall by 4%-12% by 2010. If the same policy is continued through 2020, fuel economy for new cars could improve more than 30% and stock average fuel consumption could decline by 15%- 25%. As a result, oil consumption and emissions of CO_2 would fall 12%-20%.

Policy Example: Incentives for Aggressive Uptake of Advanced Technologies

The IEA foresees great potential from technologies such as hybrid-electric and fuel-cell propulsion systems for reducing fuel consumption and CO_2 emissions. Governments can play an important role in speeding the commercialization of these technologies through targeted incentives, and in helping consumers and manufacturers gain experience with them well before 2010. For this policy example, governments would offer a price subsidy for new vehicles that meet specific criteria such as high fuel economy (set to a level that requires the use of these advanced technologies to achieve), or a combination of fuel economy criteria and the presence of specified technologies on the vehicle.

With an aggressive effort to move advanced propulsion technologies into the market, the sales share of hybrids could increase to 7% by 2010 and to 42% by 2020. (See the Aggressive production scenario outlined in Table 1.4, in which sales for fuel-cell vehicles would increase rapidly after 2020.) Those market shares could even be increased further, as the Maximum production scenario shows (Table 1.5). However, that could require measures beyond price incentives, such as requirements that a certain percentage of each manufacturers vehicles sold in a given year must achieve a specific fuel economy level or contain specific technologies such as fuel cells.

If the incentives successfully raise the share of advanced technology vehicles to 7% on new car markets in IEA countries by 2010, and to 42% by 2020, fuel economy for new light-duty vehicles would improve 5%-10% by 2010, and as much as 25% by 2020[20]. Average fuel consumption for the stock would decline by 3%-5% by 2010, and 10%-20% by 2020. Fuel consumption and CO_2 emissions would drop by 2%-4% by 2010, and by 8%-16% by 2020.

This and the previous policy example could be implemented at the same time, with effects on fuel economy, fuel consumption and CO_2 emissions that are roughly additive in percentage terms. The first policy example, focusing on conventional technologies, is likely to be more cost-effective than the second one, though, so should be implemented concurrently or first.

20. These advanced technology scenarios for fuel economy also include additional penetration of conventional technology that is cost-effective at higher fuel prices (or higher values for CO_2 reduction, such as shown in the USD 100 per ton CO_2 case in Figures 1.12 and 1.13).

2 IMPROVING THE ON-ROAD EFFICIENCY OF LIGHT-DUTY VEHICLES

While much attention is focused on the tested fuel economy of vehicles, little is given to improving their actual performance on the road. Cars do not perform as well on the road as they do on the test track, at least regarding fuel economy. Improvements in the average fuel consumption of the vehicle stock in many IEA countries have slowed in recent years and fuel consumption increases have occurred in some countries (Figure 2.1). The difference in average fuel consumption of vehicle stocks and new vehicles has been increasing, as Figures 2.1 and 2.2 show.

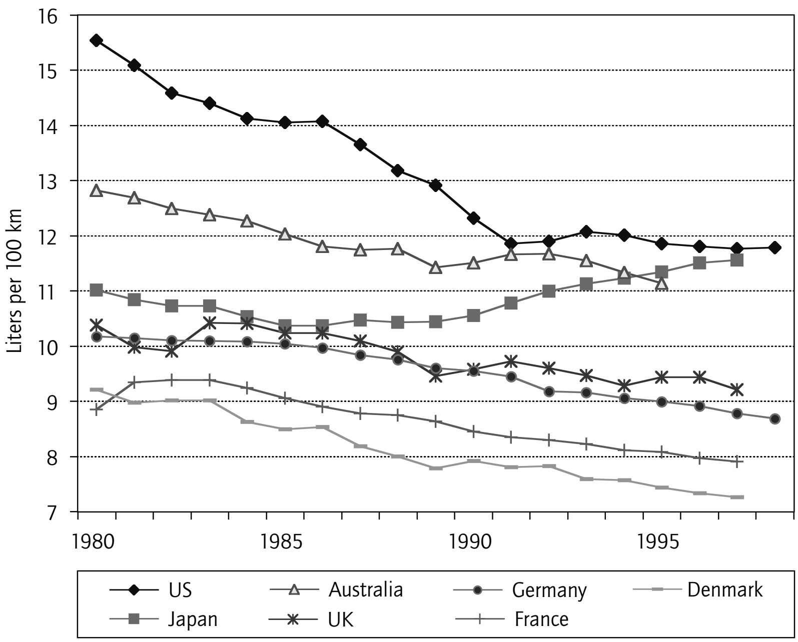
One important reason for this trend is that fuel economy test procedures have stayed the same (except for a recent change in the European test cycle, adjusted for in these figures) but on-road driving conditions have changed. The changes include:

- Increased power of new vehicles, which makes their actual usage patterns deviate more and more from test performance, as higher-performance vehicles are used at higher speeds, accelerate faster, etc.
- Increased use of accessory equipment not included in the test cycles, like air conditioning, that raises the power demand on the engine.
- Increased weight of carry-on items not included in the test vehicle, like ski carriers, items in the trunk, etc., that add weight or worsen aerodynamic drag.
- Changing driving conditions such as increased levels of traffic congestion, higher free-flow speeds on highways, and different mixes of city and highway travel.

Governments often ignore in-use fuel economy because policies to improve it are difficult to develop and implement successfully. They

Figure 2.1

Stock On-road Fuel Intensity in Selected IEA Countries, 1975-1998

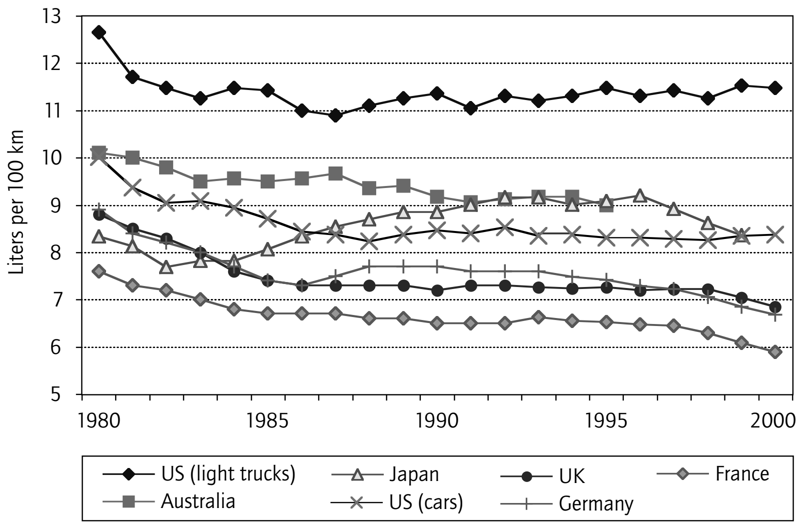


require addressing vehicles and drivers already on the road, one vehicle at a time, whereas policies targeting new vehicle test efficiency can focus on the relatively few manufacturers. Many countries have all but abandoned efforts to improve in-use fuel economy in recent years, though a few IEA countries have undertaken initiatives in this area to save oil and reduce CO_2 emissions. Types of measures include:

- Vehicle inspection and maintenance programs that incorporate fuel efficiency goals.
- On-board equipment that helps drivers better understand the fuel consumption of their vehicles and how to improve it.

Figure 2.2

New Car Test Fuel Economy in Selected IEA Countries, 1980-2000



- Speed limits that encourage highway travel at speeds optimal for fuel economy.
- Expansion of roadway capacity and improvement of traffic flow to reduce congestion and stop-and-go driving, which lowers fuel economy.
- Vehicle retirement or scrappage programs that would eliminate older vehicles with lower-than-average fuel economy.

We explore each of these areas and provide policy examples in each area in the following sections of this chapter.

Vehicle Maintenance

The proper maintenance of vehicles by owners and operators continues to be important for ensuring optimal efficiency and fuel consumption.

The role of the owner-operator is becoming less important than in the past, mainly because most vehicles are now designed to operate near peak efficiency without any maintenance for at least the first 50 000 km. In particular, the need for tune-ups has been nearly eliminated. Owners still play an important role in some areas, such as checking the oil, the condition of the filters and tire pressure, which, if left unattended, can reduce fuel economy. In the future, the increase in the use of on-board diagnostic equipment, discussed below, will help owners identify problems that reduce fuel economy. To the extent that owners properly respond to signals provided by such equipment, the need for additional policy measures in this area may be minimized.

The most widely used approach to promoting improved vehicle maintenance is a combined mandatory vehicle inspection and maintenance program. Many countries have programs that include testing for emissions, although few appear to directly target fuel economy. Adding tests for fuel economy to such programs could be a low-cost method for minimizing fuel use and CO_2 emissions. Repairs to poorly maintained vehicles with high emissions can often, but not always, improve fuel economy. For example, fuel economy will usually improve if a problem resulting in high CO_2 emissions is repaired, but can sometimes worsen if it is related to high hydrocarbon or nitrogen oxide emissions. Inspection and maintenance programs also present an opportunity for adding an element of driver education or awareness of the benefits of fuel-efficient driving practices and regular vehicle maintenance, like maintaining proper tire pressure.

A recent review of inspection and maintenance programs focusing mainly on pollution emissions of light-duty vehicles in several states of the United States and provinces in Canada (HBC 1999) shows that fuel economy improved 2%-6% as an incidental effect of vehicles that failed tests and were then repaired. (Failure rates ranged from 10%-20%). Fuel economy improved as much as 13% for older vehicles, but tended toward the lower end of a 2%-6% range for more recent vehicles. Fuel economy for the fleets of tested vehicles improved an 0.2%-2.5%. The study found that none of the surveyed programs even included tests for CO_2 emissions or fuel economy. Therefore, including such tests and repairing failures directly related to fuel economy (such as replacing worn spark plugs or inflating tires low on air) could lead to even better results.

Policy Example: Enhancing Inspection and Maintenance Programs

Existing inspection and maintenance programs could be enhanced to include inspection of fuel economy and components affecting fuel economy (such as air filters and spark plugs) and required maintenance (e.g. tune-ups) for vehicles that fail these elements of the inspection. Programs that already include emissions in general improve fuel economy at least 2% and perhaps up to 3% to 4%, the HBC study shows. Adding elements targeting fuel economy could increase this by at least a further 1%-2%. However, the size of this improvement may decline through time as advanced on-board diagnostic systems help drivers identify problems themselves, and as new cars are increasingly designed to be maintenance-free for the first 100 000 km or more. If an existing inspection and maintenance program adds a fuel economy test and maintenance requirements, fuel economy will improve and CO_2 emissions will decline by 1%-2%, but probably less so after 2010, by zero to 2%.

Cost and Other Considerations

Estimates of the cost of reducing air pollutants through inspection and maintenance programs vary widely and depend on assumptions such as the value of reducing emissions with the goal of improving air quality (Paine 2000). No cost estimates were found that focus on, or even include, reducing fuel use and CO_2 emissions. Adding a fuel economy component to an existing inspection program could be relatively inexpensive. Especially after accounting for the value of fuel savings, the net cost of maintenance to improve fuel economy can be very low or negative. The cost of adding air to tires, changing filters and

Driver Training Programs: Canada's Auto$mart Program

Natural Resources Canada's Auto$mart program aims to educate motorists on buying, driving, and maintaining vehicles while keeping fuel consumption in mind. It offers drivers various publications and a car economy calculator, which allows them to measure and improve the real-time fuel consumption of their vehicles.

Auto$mart recently introduced an outreach program to address the specific information needs and awareness levels of novice drivers. The Auto$mart Student Driving Kit reaches over 500 000 students each year in driver-training programs across Canada; 80% of those students are under the age of 21. The Auto$mart Student Driving Kit includes educational resources for trainers that help them integrate fuel-efficient driving techniques into their programs.

Source: http://autosmart.nrcan.gc.ca/home_e.htm

spark plugs, for example, is generally offset by fuel savings. Engine tune-ups to older models can also be cost-effective.

On-board Driving Technology and Driver Training

The combination of on-board equipment, which gives drivers information on the fuel economy of their driving or even regulates fuel economy, and a training strategy to help drivers improve their fuel efficiency, could substantially improve the on-road fuel economy of new and existing vehicles. A recent workshop by the European Conference of Ministers of Transport (ECMT 2000) on non-vehicle measures (i.e. those related to driving behavior) for reducing emissions identified five ways drivers can enhance fuel economy:

- Reducing rates and cycles of deceleration and acceleration (identified as a key area for improvement).

- Keeping engine revolutions low, 1 500-2 000 rpms. This can be achieved by shifting to higher gears sooner during acceleration.
- Shutting off the engine when idling for more than one minute and, for newer cars with fuel injection, starting the engine without pressing the gas pedal.
- Reducing maximum speeds.
- Maintaining proper tire pressure.

Improvements in these areas reduced fuel consumption per kilometer an average of 15% and as much as 25% for some drivers, according to one driver training institute (Schwarz 2000). On-board technology and driver training programs can help drivers in all these areas.

Driver training programs that address fuel economy can target small groups, like commercial truck drivers working in company fleets, or larger publics, like those preparing for a written test to obtain a driving license. Courses can be short and narrowly focused or long and comprehensive. A one-time course on fuel-efficient driving practices could address reduced idling time, moderate accelerations, proper tire pressure, engine maintenance, and shopping for fuel-efficient vehicles. The major problems with such courses, however, appear to be motivating drivers to participate and achieving lasting changes in driving habits.

On-board driving technology relevant to improving fuel economy includes a variety of instruments that measure and inform drivers of their fuel economy (as well as other characteristics of their driving). These fall into two main categories. The first, econometers, measure the rate of fuel consumption of the vehicle and report it to the driver in real time. These devices, in the form of an analog dial, became popular in the 1970s but began to disappear in the 1980s as fuel prices dropped and concerns about energy efficiency diminished. These are often placed within the driver's direct line of vision (e.g. high on the dashboard). Thus, drivers receive continuous signals about how their driving style affects fuel consumption. For example, quick starts and stops as well as speeds above 80-90 km per hour put the analog dial into the "red zone" signaling high consumption.

The second type is the on-board computer. These usually use a digital readout and can measure fuel use in real time and report it to drivers. They usually also relay other information including average driving speeds, driving time, time left before fuel is depleted, average fuel consumption during the current trip, distance covered since refueling, etc. Although these digital readouts offer more information to the driver, they could affect driving style less than econometers since on-board computers do not always show instantaneous fuel consumption and are generally placed outside the direct line of sight of the driver.

Other on-board driving technologies, mainly cruise control technologies, can regulate driving itself. The more a vehicle runs at a constant speed, the more fuel-efficient it is, and since all cruise-control systems set

On-board Diagnostic Research and Outreach in the Netherlands

Several government agencies in the Netherlands are co-operating to conduct a program to promote and test on-board diagnostic equipment (NOVEM 1998). This is part of a larger effort, managed by NOVEM, the Netherlands Agency for Energy and the Environment, to promote fuel-efficient driver behavior. (The effort was called "Buy Eco-wise, Drive Eco-nice" until 1999 and then "The New Driving Force"). The equipment program has investigated techniques for the improved marketing of three on-board diagnostic items: cruise control, econometers, and computers to vehicle shoppers. The aim of the program is to reduce CO_2 *in the Dutch transport sector by 3% relative to a no-action case. NOVEM estimates that these three items, plus better enforcement of speed limits, can reduce fuel use per kilometer for vehicles in the program by 10%. An earlier NOVEM report focusing on just two technologies, cruise control and econometers, found that each one alone could boost fuel savings up to 12% for private, that is, non-commercial, drivers (NOVEM 1995).*

speeds for vehicles, they directly improve fuel use. Advanced cruise-control systems, beginning to enter the market, also can control and moderate rates of acceleration and deceleration, which can make an important contribution to saving fuel. Since advanced systems are sensitive to braking and shifting, they can be used in denser, stop-and-go traffic that simpler systems cannot tolerate. One advanced technology system, the autonomous intelligent cruise control system, automatically takes into account the distance and/or speed of other vehicles and adjusts speed accordingly. This system is expected to begin appearing on a number of vehicle models in the next few years. A form of this technology is already available on some models in Europe and Japan (United Kingdom Ministry of Transport 2001).

Cruise control devices have a more direct effect on fuel consumption than do training programs, as they do not depend on driver attitudes about saving fuel or achieving long-term changes in driving habits. NOVEM (NOVEM 1995) conducted tests of fuel savings associated with the use of different equipment and found savings per kilometer of 13% for econometers and 12% for cruise control for private drivers (and rates of 5% and 4% for commercial drivers). It is unclear what the combined savings of cruise control and the econometer would be. Although these two technologies perform some of the same functions, they are largely complementary. An econometer is most useful during acceleration and deceleration in stop-and-go driving, while regular cruise-control systems are helpful mainly for highway driving. In testing a package of on-board technologies and lower speed limits, a later NOVEM report (NOVEM 1998) found that fuel use per kilometer declined an average of 10%, a lower result than for the 1995 study.

Policies to Encourage Increased Driver Awareness and Use of On-board Technologies

Driver-training programs present two difficulties: involving significant numbers of drivers and ensuring that the lessons learned are not soon forgotten. While many countries have tried to increase the numbers of drivers trained over the years, through various kinds of marketing campaigns and initiatives, several newer approaches appear promising:

- Making knowledge of energy-efficient driving techniques part of the written and practical tests for obtaining a driving license.
- Encouraging the development of secondary markets for econometers and promoting their purchase for existing vehicles through pricing and marketing techniques.
- Working with original equipment manufacturers to increase the use of on-board technologies in new vehicles.
- Providing incentives for or requiring that new vehicles are equipped with cruise control and/or econometers.

Policy Example: Improving Driver Fuel Efficiency through Training Programs

If a driver-training program could improve the driving habits of half of its students so that their average fuel consumption declined by 5%-10%, fuel savings would increase 2.5%-5% per enrolled driver. A large driver-training program might, over time, reach 20% of the population. If so, it would reduce fuel use and CO_2 emissions by 0.5%-1% in the passenger vehicle sector. This policy could target existing programs, like driver-education classes in schools. It could be reinforced with questions about fuel-efficient driving on the written test for the drivers license. Reaching 20% of the driving population would take several years but could possibly be accomplished by 2010.

Policy Example: Promoting On-board Technologies that Improve Fuel Economy

An alternative or complementary policy to driver training would be to encourage or even require cruise control and/or econometers on new vehicles, possibly along with other on-board technologies, such as warning lights for under-inflated tires. These could be required as standard equipment in all new cars sold within a country or promoted through incentives, e.g. a reduction in registration fees for vehicles equipped with the technologies. In countries that already have a high penetration of cruise control (such as the United States) the policy could focus on other technologies such as econometers, tire pressure indicators, and advanced cruise-control systems. We estimate, conservatively, that a package of on-board technologies could result in 5%-10% fuel savings per vehicle. If it is assumed that 25% of new cars are already equipped with a package and that, with the new policy, all new cars would carry them, by 2010 average fuel use and CO_2 emissions for new light-duty vehicles could decline by 4%-8%, but just by 2%-5% for the entire stock, since new cars comprise a small part of the stock. However, a program could reach older cars if it included incentives for retrofitting existing vehicles with on-board technologies. That could speed up the overall rate of improvement. Since the number of vehicles with these technologies may rise over time even without government policies to encourage or require them, most of the benefits of this policy might be realized in the coming decade.

Cost and Other Considerations

The direct costs and benefits of driver training and on-board technologies are the costs of the technology and the training, and fuel-savings benefit. (There are also likely to be other indirect costs and benefits, such as on safety). The IEA was not able to obtain reliable estimates of driver training programs, but a general estimate for the cost of intelligent cruise-control systems is USD 300-USD 350 (Institute of Transportation Engineers 1996). If this estimate is correct for a system that saved drivers 5% of fuel use per kilometer, then for many drivers this technology would more than pay for itself in fuel savings over the life of their car, even using a substantial discount rate for future fuel savings[21].

21. For example, a driver who travels 15 000 km per year with a car using 10 liters of fuel per 100 km of travel, with fuel at a price of USD 1.00 per liter would save USD 75 per year, resulting in a four to five-year payback.

Speed Limits and Enforcement

Lowering speed limits and improving enforcement of existing speed limits are among the most discussed but most difficult to implement of any transportation measure. In many countries, average highway speeds have actually been increasing rather than decreasing in recent years. Lowering average highway speeds can save fuel because vehicles are at their most efficient between about 80-90 km per hour; various studies show that fuel economy declines at both lower and higher speeds. Periodic tests conducted by the United States Department of Energy (Figure 2.3) suggest that fuel economy at higher speeds is better than it was ten years ago. Still, the data show that even for recent vehicles, fuel consumption is 30% higher at speeds above 120 km per hour than at 90 km per hour. Since many vehicles in Europe (and in some rural areas in North America) travel at speeds well in excess of 120 km per hour, the loss in fuel economy may be much greater.

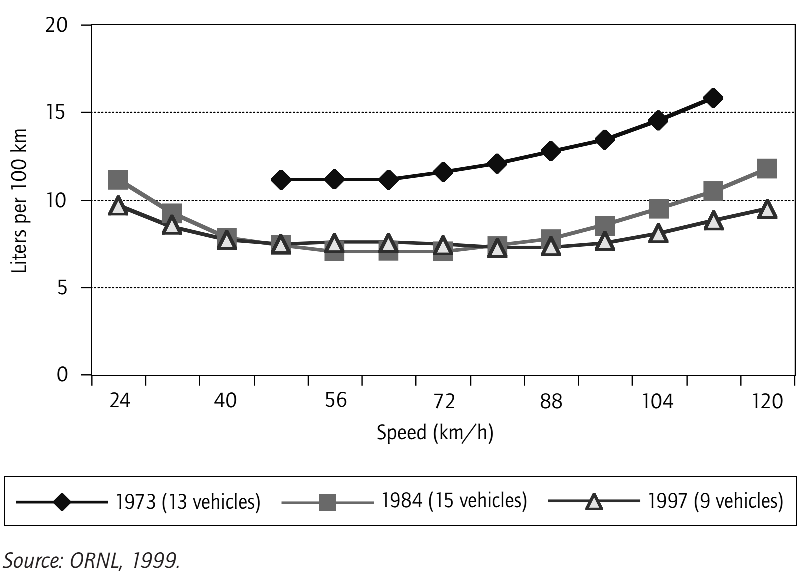
In the United States, the national speed limit of 55 miles per hour (about 90 km per hour) was eliminated in 1997. A study by Pechan (Pechan 1997) projected that as a result, nitrogen oxide emissions on highways in the country would likely increase by about 5%. (No estimate for fuel consumption was made). A much earlier study by the United States National Research Council (NRC 1984) estimated that the national speed limit cut fuel consumption by 2.2%, as previous speed limits in most states were higher than the national one.

While lowering speed limits is often politically unpopular, better enforcement of existing speed limits may receive more support. In many countries, average vehicle speeds on highways are well above the posted limits. For example, on urban interstate highways in the United States with posted speed limits of 55 miles per hour, an estimated 70% of vehicles travel above the limit, with an average speed of 7% above the limit. On rural interstates with posted speed limits of 55 miles per hour, 78% of vehicles travel above the limit at average speeds of 22% above (Pechan, 1997). The effect of improved enforcement of speed limits on fuel consumption and emissions of course depends on the extent of the program and compliance with it. A study conducted by NOVEM in the Netherlands estimated that if all drivers in that country respected the existing speed limits, fuel use would drop by 5%.

New technologies and approaches to speed limit enforcement have become available that could aid countries in formulating an effective policy. Many countries are finding that remote sensing systems, with automatic ticketing of violators, is an attractive option. A few countries, like the United Kingdom, employ the technology in many areas (see box). Radar systems, the traditional method used by police for remote sensing of speeding, have become more sophisticated but still are not fully automatic – they cannot fully identify individual vehicles and their speeds without the guidance of a person. Camera and laser technologies, however, can single out violators among a group of vehicles or in a particular lane of traffic, making it an effective remote

Figure 2.3

Fuel Economy as a Function of Vehicle Speed: US Tests in Three Different Years



Source: ORNL, 1999.

Use of Speed Limit Enforcement Cameras in the United Kingdom

Cameras are used to enforce speed limits in the United Kingdom mainly for areas prone to speed-related accidents, but in recent years they have become more widely deployed. Speed detection by cameras can result in ticketing, fines, and points on drivers' licenses. Newspaper articles indicate that in some areas, many motorists have been ticketed through this system.

Studies on the success of cameras in achieving their main objective – reducing accidents – suggest that they are effective. One survey, Hooke et al. (1996), found that accident rates fell by an average 28% at 174 camera sites. Several studies found a significant effect on reducing speeding and lowering average vehicle speeds in areas with cameras. Corbet and Simon (1999) reviewed several such studies and found average speed reductions of 3-8 km per hour. Their own study of responses over time showed that by two months after installation most drivers had slowed down somewhat, and by eight months almost no drivers had increased their speeds again. However, It is unclear from these studies whether the effects on average speeds extend beyond the immediate vicinity of the cameras.

Drivers in the United Kingdom appear to have a generally favorable attitude toward speed cameras. Surveys by Corbet and Simon (1999) indicate approval rates around 65% both before and after installation of cameras. Not surprisingly, approval rates for those who state that they follow speed limits tend to be much higher than for those who admit to breaking the speed limits.

enforcement strategy even in heavy traffic. Laser technology is unaffected by radar jammers, cannot be picked up by radar detectors, and is accurate to within 2 km an hour.

Even more advanced, and potentially more controversial, approaches to speed enforcement are being researched and tested. One of the most promising is *urban drive control*, a project funded by the European

Commission that has reached the commercialisation stage. The project involves creating a central control system that records data about road conditions and calculates safe vehicle speeds for them. This information is then sent to vehicles via transponders or another transmission system. Thus, the central control center can transmit real-time speed limits directly to the driver via a dashboard display, or can even directly control the maximum speed of vehicles equipped with a compatible cruise control system. Such a system could also take into account data from sensors on the vehicle.

Thus, there are no major technical obstacles to remote speed enforcement. Whether it will become a viable approach in many countries depends primarily on overcoming social and political issues related to privacy and objections by *drivers' rights* advocates.

Policy Example: Reducing Speed Limits

The effect of a reduction in speed limits on fuel consumption is dependent on a number of factors including initial conditions such as speed limit, speed distribution of vehicles, the percentage that are in violation (speeding) and rates of compliance to a change in the law. We make a general estimate for a decline in fuel consumption based on the following hypothetical situation: A country reduces its posted speed limit by 10 km per hour on highways with existing limits of 110-130 km per hour. Good enforcement reduces average speeds of the fastest half of traffic by 10 km per hour and thus average speeds of all traffic by about 5 km per hour. Assuming a 1% increase in fuel use for every 1 km per hour increase in speeds above 90 km per hour (based on the United States Department of Energy estimates), fuel consumption would decline about 5% for roads covered under such a policy. If affected highways account for 20% of all vehicle traffic in the country, this policy would reduce average speeds 5% and fuel use by about 1%. These calculations take into account that highway travel usually accounts for one-third to one-half of total vehicle travel, and that in many countries posted speed limits on some highways, such as urban highways, are already lower than for other ones.

Cost and Other Considerations

The cost of this measure is quite low or negative in the simple sense that fuel savings would very likely be greater than the increased cost of enforcement. However, a more complete analysis would need to consider the value of lower speed limits on lower accident and mortality rates and longer travel times.

Traffic Flow and Roadway Capacity

Enhancing the capacity of the roadway system and its flow of traffic have been among the principal policy objectives for transport system planners over the past 50 years. Most cities of the world have dramatically expanded their roadway systems to accommodate increases in the number of vehicles and traffic volumes over this period. Traffic flow improvements encompass a wide range of approaches, including:

- Improvements to the timing of traffic signals to reduce delays at intersections in urban areas.
- Advanced technologies for managing incidents and sensing traffic conditions that allow faster responses to breakdowns and accidents on the road, and that can deliver real-time information on traffic conditions, directions, and identification of alternative routes to drivers.
- Expansion of roadway capacity, from adding a lane on an existing roadway to building an entirely new roadway segment.

All these approaches represent capacity enhancements since they increase the ability of the roadway system to accommodate traffic. They are generally targeted at reducing congestion, increasing average speeds and reducing stop-and-go driving. Therefore, capacity enhancements usually improve the average on-road efficiency of vehicles in the system and reduce fuel consumption per kilometer of travel. As such, capacity enhancements and traffic flow improvements have often been justified as a way to reduce fuel consumption and pollutant emissions. However, a growing body of research suggests that an important secondary effect of capacity enhancements is that they encourage more driving. This phenomenon has been called *induced demand*. It is based on the economic idea that increases in average speeds and reductions in travel times reduce the cost of travel and can in turn trigger:

- Changes in routes and times of departure, and even destinations.
- Shifts from public transit and non-vehicle travel to private vehicles.
- Long-term relocations and changes in patterns of development that may increase the number and distance of vehicle trips over time and, thus, overall travel.

If the induced demand response is large, some or all of the energy savings of improved system efficiency and increased vehicle speeds could be lost over time to increases in travel. A number of recent studies have analyzed the relationship between adding roadway capacity (often measured as increases in lane-kilometers) and changes in travel (apart from those that would have occurred anyway). Studies such as Fulton et al. (Fulton 2000) and Lem and Noland (Lem 2000) suggest an elasticity for travel increases as a function of increases in lane-kilometers of capacity on the order of 0.3-0.5 in the short run and as high as 0.9 in the long term. The latter figure suggests that most of the congestion reductions and higher speeds gained by capacity expansion eventually may be lost to increases in traffic.

Studies that model the transport network have furthermore estimated how increased travel may offset fuel savings from improved traffic flow. Two recent European modeling efforts have estimated that, in fact, virtually all of the fuel savings from capacity expansion is lost to increases in travel. Modeling results from the European Commission Auto-oil non-technical measures study show that increasing road capacity by 5% to improve traffic flows has a net effect on fuel savings of about zero. The study found a 0.5% increase in private vehicle travel that offset the fuel savings from a 1.5% rise in average vehicle speeds, which in city traffic helps reduce fuel use (European Commission 2000). NOVEM, the Dutch Environment Agency, which carried out travel modeling for the Netherlands in a joint effort with Belgium, found that a policy of "provide roads to meet demand" would raise transport emissions of CO_2 by a net 9% between 1990 and 2010, compared to a *no new roads* policy (as cited in OECD 1996).

Nonetheless, traffic flow improvements tend to be politically popular and yield considerable benefits beyond reductions in fuel consumption and emissions, namely increased mobility and, for a while at least, reduced travel times. It is unclear, however, whether capacity enhancements should be part of a strategy to reduce fuel use or CO_2 emissions, since they tend to encourage more auto travel.

Urban Traffic Information Service in Paris, France

In congested urban areas, drivers need current traffic information before they start a trip so that they can make informed decisions regarding routes and travel times. In Paris and its surrounding area, road traffic has multiplied by a factor of 2.2 in the last 20 years. On expressways, traffic congestion has increased by 16% per year. Eighty percent of the traffic jams in France occur in metropolitan Paris, half of which are due to unforeseeable situations such as accidents and breakdowns.

A service known as Mediamobile, commercially available since October 1997, offers drivers in the Paris region state-of-the-art, real-time traffic information on estimated transit times and optimal routes based on current road conditions, accidents, and lane closures. This service is provided via a computer and monitor on board participating vehicles. Mediamobile's computer uses standard telematic technologies such as GSM (global system for mobile communications) and RDS/TMC (radio data system/traffic management channel), thereby enabling compatibility with evolving services. This is the first such service in a European city.

Source:
http://158.169.50.95:10080/telematics/success/mediamobile.html

Due to the uncertainty of the net effect of measures to increase roadway capacity on travel and fuel use, no policy example was developed for this area.

Vehicle Scrappage Programs

A number of programs in IEA countries in recent years have attempted to improve air quality and average vehicle fuel economy through *early retirement* or *scrappage* programs. These programs generally involve offering, to the owners of older but still operable vehicles, incentives to remove their vehicles from the road and turn them over to be scrapped. Since old vehicles tend to be disproportionately high emitters of air pollutants, such an approach has considerable appeal, as it can focus on removing the dirtiest vehicles from the road and in the process promote the sales of new, much cleaner vehicles. However, since in most IEA countries new cars are not much more fuel efficient on the road than 20-year-old vehicles, the effect of most scrappage programs on fuel savings and reduction of CO_2 emissions may be small.

Scrappage programs generally have not been conceived with fuel economy in mind. A recent survey by the European Conference of Ministers of Transport (ECMT) of vehicle scrappage programs in ten IEA and non-IEA countries indicates that only one program in Italy targeted improved fuel economy (in addition to air pollutants) as an explicit objective. (See box and Table 2.1 for a summary of their findings). None of the programs appears to have made estimates of resulting reductions in CO_2 emissions.

Nearly all the programs have required scrapped vehicles to be at least ten years old and offered incentives of USD 500-USD 1 500 per vehicle. One difference among the programs is their duration; most have lasted less than two years, but several, such as the second Italian program, are continuous. Short-term programs attempt to quickly eliminate the oldest, dirtiest vehicles from the road by creating a sense of urgency among owners to act. There is some evidence that, after a

Table 2.1

Characteristics of Vehicle Scrappage Programs in IEA Countries

Country	Dates of program	Vehicles eligible	Incentive	New car purchase required?	Number of vehicles scrapped
USA-California (Unocal program)	1990	Pre-1971 cars only	USD 700 offered per vehicle.	NO	8 376 cars and light trucks
Canada-British Columbia	1996	Pre-1983 models, recently failed emissions test	Free transit pass for one year (worth about USD 700), or rebate of USD 550 for new car or USD 400 for recent model used car	NO	
Greece	1991-1993	Older than 10 years	40%-60% reduction in excise tax on new cars	YES	
Hungary-Budapest	1993 through present	Two-stroke engine cars and trucks (mostly very old)	USD 500 or a one year pass for public transit network	NO	
Denmark	1994-1995	Older than 10 years	USD 1000		100 000 cars
France	1994-1996	Older than 10 years (lowered to 8 years in 2nd year)	USD 950	YES	700 000 cars (estimate net of expected natural retirements)
Spain	1994-1996, then restarted in 1997 and continued through present	Older than 10 years (lowered to 7 years in 2nd year)	USD 630-USD 750	YES	1994-1995: 175 000 cars (estimate net of expected natural retirements)
Ireland	1995-1997	Older than 10 years	USD 1 500	YES	60 000
Norway	1996	Older than 10 years	USD 800	NO	150 000 (net of expected natural retirements)
Italy	1997		USD 900-USD 1 200 plus matching reduction in new car price by dealers	YES	
Italy (2)	1998 through present		USD 900 for purchase of new vehicle with fuel economy of less than 7 liters per 100 km, USD 750 for 7-9 liters per 100 km; bonuses for purchases of new alternative-fuel vehicles		

Source: Table developed by IEA based on ECMT, 1999.

Vehicle Scrappage Programs in Italy

Italy is among the most recent European countries to have introduced incentives for accelerated vehicle retirement. From January to September 1997, the government awarded incentive payments for scrapped vehicles from ITL 1.5 million to ITL 2 million (about USD 900 to USD 1 200 at that time). The specific amount was related to engine displacement. The incentive was conditional on the purchase of a new car and on a reduction in the car's price by the manufacturer or dealer equal to the bonus. When the program expired, it was extended for four months with a fixed bonus of ITL 1.5 million for all car sizes. For the year 1997, about 1 148 000 old cars (about 4% of the Italian fleet) were retired under the program.

From February to September 1998 a second program was introduced. This time two slightly lower incentive levels, ITL 1.25 million and ITL 1.5 million, were offered, with the amount dependent on the fuel consumption of the replacement vehicle. The higher amount was awarded if the new vehicle used less than 7 liters per 100 km or if it was powered by liquid petroleum gas (LPG), compressed natural gas (CNG), or electricity. The lower incentive was provided for vehicles using 7-9 liters per 100 km.

Unfortunately, there are no available data on the fuel use or CO_2 emissions impacts of these programs, scrappage rates clearly rose sharply after the first program was initiated. For vehicles aged 10-13 years, the scrappage rate in 1997 was about 2.3 times higher than in each of the previous four years. How increased scrappage rates translate into reductions in fuel consumption and emissions reduction, and whether all of these effects are durable, is unclear.

Source: ECMT 1999.

short-term program ends, the characteristics of the vehicle stock rebound to near where they would have been without the program. For example, Fontana (ECMT 1999) notes a surge in the sales of new vehicles in Italy after the initial program was begun followed by a decline afterward. The surge and decline in sales nearly cancel each other out. This phenomenon suggests that scrappage programs, especially short-term ones, may accelerate retirements but not change the long-run structural composition of the stock. If so, then the environmental benefits they provide are temporary. However, in the case of CO_2 emissions, which are long-lived, one or two years of reduced emissions may make a long-term difference in the total amount of CO_2 in the atmosphere.

As long as average on-road fuel economy for new vehicles is similar to that of vehicles more than ten years old, obtaining large effects on fuel economy and CO_2 emissions of a country's vehicle stock through scrappage programs will be difficult. A highly targeted program might require replacing cars of low fuel economy with higher fuel-economy models, perhaps requiring a minimum fuel economy improvement, but such a program would be limited by the number of old, low fuel economy cars in existence, which may be small in many countries. On the other hand, if rapid improvements to new vehicle fuel economy occur in the future, which could happen in Europe as a result of the voluntary commitment by European automobile manufacturers to reduce CO_2 emissions from new cars by 25% by 2008, the difference between new and old car fuel economy may be great enough to make a targeted scrappage program worthwhile.

Because scrappage programs currently appear to have little effect on the average fuel economy of vehicle stocks, no policy example was developed for this area.

3 REDUCING LIGHT-DUTY VEHICLE TRAVEL

Growth in vehicle travel is the principal factor behind increases in fuel use for light-duty vehicles. Given the small improvements in new vehicle fuel economy that we noted in Chapter 2 and the flat or even slightly declining on-road efficiency noted in Chapter 3, growth in light-duty vehicle fuel consumption and CO_2 emissions during the 1990s closely tracked increases in vehicle travel.

Growth in vehicle use in IEA countries remained strong during the 1990s, rising more than 10% in many countries and by more than 20% in a few. Some countries, like Japan, which had low growth rates before 1990, have seen the highest growth rates since. In contrast, the United States, with the highest level of vehicle travel per capita in 1990, has had comparatively modest increases since then (Figure 3.1).

Light-duty vehicles are the dominant mode of surface passenger travel with more than an 80% travel share in nearly every IEA country, compared with bus and rail travel (Figure 3.2). Even Japan, which relies extensively on rail for commuter and intercity travel, has a light-duty vehicle travel share of nearly 60%.

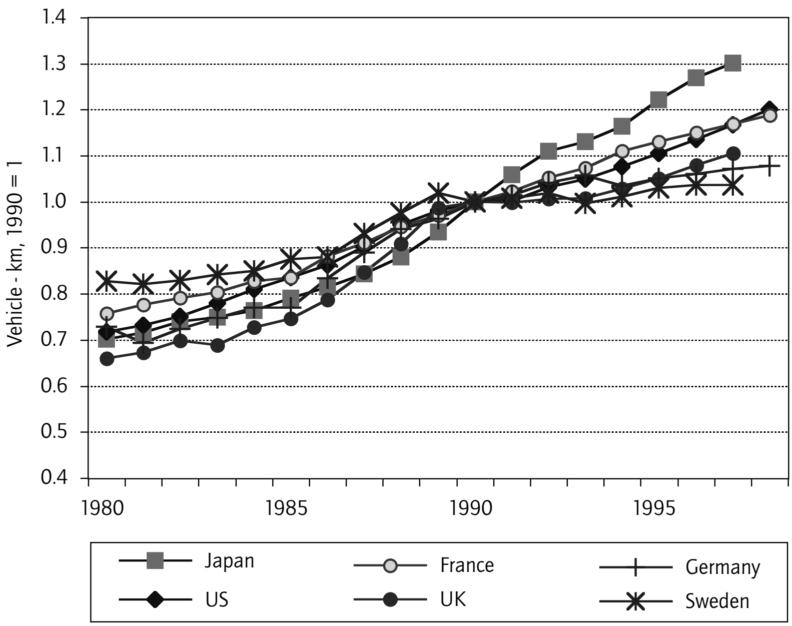
This chapter considers six different approaches to reduce or slow growth in travel by light-duty vehicles that fall into two categories: those that discourage such travel and those that encourage alternative modes of travel that may be more energy efficient. The final section considers the effect of a combination of policies on reducing vehicle travel. Because travel reduction policies are often developed at the local and regional levels in most countries, the role of national governments in implementing some of these policies may be limited. National governments could, however, encourage localities to undertake any of these measures to reduce vehicle travel by:

- Providing localities with guidelines or information.

Figure 3.1

Vehicle Travel Growth in Selected IEA Countries

(1990 = 1)



- Earmarking funds or subsidies for certain types of measures like reductions in transit fares or investments in transit, bicycle or pedestrian infrastructure.
- Linking funding for localities with local reductions in CO_2 emissions.
- Increasing taxes on fuels or vehicles, or linking taxes to vehicle/fuel CO_2 emissions, and earmarking the revenues for improving transit or non-motorized travel infrastructure.

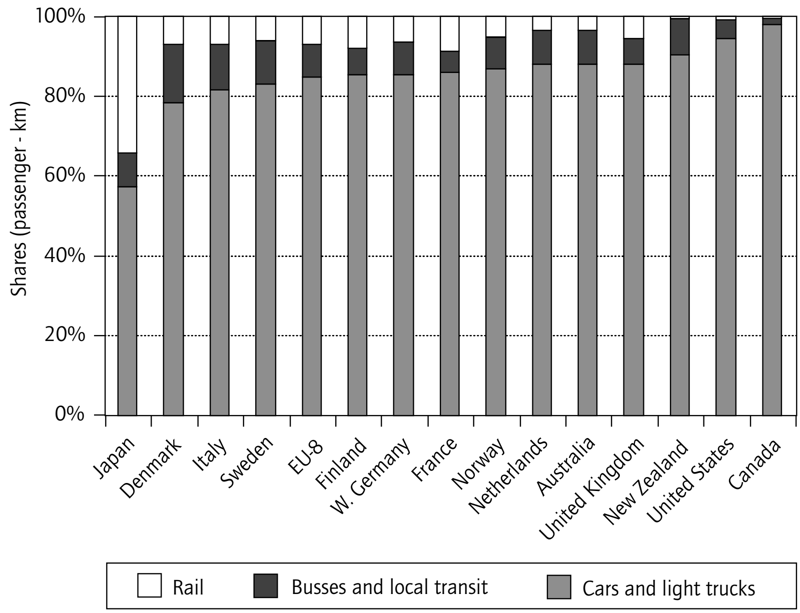
Improving Transit Systems

The basic goal of improving transit systems, with respect to CO_2 reductions, must be to increase ridership and load factors. Hagler Bailly

Figure 3.2

Passenger Travel Shares by Motorized Modes, Selected IEA Countries, 1995

(shares of passenger kilometers traveled by mode)



Canada (HBC 1999) identified four areas that policy makers can consider to achieve this: adding to and expanding the transit infrastructure, improving transit service on existing systems, developing pricing strategies to make transit more attractive to riders, and adopting various innovations to improve transit service.

Expanding transit capacity may have the greatest potential for shifting riders from private vehicles, but by itself has uncertain potential for reducing CO_2 emissions. Expanding transit capacity increases the energy consumption of the transit system, but may not attract sufficient new ridership to offset this increased energy use through reductions in the energy use of other vehicles. This is a concern particularly in places where the average energy intensity of transit is not much lower than that of light-duty vehicles, such as in the United States.

While most data indicate that bus and rail travel in most countries is less than half as energy intensive per passenger kilometer as light-duty vehicles, this may be misleading[22]. Data for France and the United States comparing automobile energy intensity to that of urban bus and rail transit systems (and that exclude school buses and intercity bus and rail) suggest that the difference in energy intensity is much smaller[23]. Passenger load factors on transit systems, especially bus systems, have been declining in recent years in many countries and energy intensity per passenger over the past two decades has risen. This compares to a general improvement in the energy intensity of light-duty vehicles over this time. Thus in many countries the efficiency advantage of urban transit systems is diminishing relative to private vehicles. Under these conditions, expanding the capacity of transit systems without ensuring a large modal shift to transit may not yield reductions in CO_2 emissions. Luring more passengers onto existing transit systems may be a better way to reduce energy use and emissions.

Another obstacle to saving energy through increased transit use is that most transit systems account for a low percentage of total metropolitan passenger travel. So even a large percentage change in ridership may result in a small reduction in private vehicle use. The extreme case is the United States, where transit bus and rail systems account for about 3% of passenger kilometers traveled. In the US a doubling of transit ridership would reduce vehicle travel by 3% or less, since the new riders would likely include those making additional trips and mode switching

22. The wide variation in this ratio for different countries may reflect different compositions of bus and rail travel. Member country data submissions to the IEA usually include energy use and passenger travel for all bus and rail within the country, including intercity coaches, school buses, and long-distance rail. These bus and rail services generally achieve much higher load factors and lower energy intensity per passenger kilometer than urban bus and rail transit.

23. The energy intensity ratio of light-duty vehicle to transit bus and rail for France is less than 2 to 1, while for the United States the ratio is nearly 1 to 1. In the United States, transit buses are slightly more energy intensive than light-duty vehicles per passenger-kilometer.

by those who formerly walked, biked, or (in the case of rail) rode buses. Increasing ridership on rail transit, in particular, often draws much of its new ridership from bus transit. Even in European countries, transit systems comprising bus, metro, rail and tramways account for an average of less than 10% of passenger kilometers traveled[24].

Improving Transit Service in Copenhagen, Denmark

Copenhagen already has one of the highest shares of transit ridership and lowest shares of personal vehicle travel in the world. Even so, Copenhagen Transport has embarked on a plan to modernize public transit facilities and increase ridership by 50% by the year 2005 to address an expected surge in passenger travel. The plan, known as "Vision 2005", focuses on improving mobility in the city in line with the government's environmental goals that require reduced carbon dioxide emissions, no increase in automobile traffic in cities, and improved conditions for public transportation. Copenhagen Transport plans to achieve this by improving and offering new public transit services, as well as reducing the cost of transit, thereby drawing new riders from those who currently drive or ride in private vehicles.

Making bus transit more attractive to the public is an important element in the program. Copenhagen Transport is replacing old equipment, expanding its express bus service, adding a global positioning system to provide more accurate, real-time information for passengers and instituting signal priority and more reserved lanes for buses. Displays at bus stops will show the time until the next bus arrives and displays in buses will inform passengers of the next stop and connecting buses and trains. Other improvements include improved lighting and pedestrian access at bus stops.

Source: http://www.apta.com/intnatl/intstudy/tcrp27b.htm

24. Average for the European Union. Shares in some individual countries, like the Netherlands, are above 10%.

Nevertheless, improving transit can be a critical element in an overall plan to reduce vehicle travel. Transit improvements can yield important benefits for the entire transport system, but these are often difficult to quantify. Many of the most important benefits of transit expansion occur over the longer term. For example, improving transit infrastructure may encourage denser land-use patterns (and can be coordinated with land development) and may therefore lower rates of car ownership and use.

Bus systems are relatively easy and inexpensive to expand through the addition of more buses and drivers to the existing roadway system. The more developed a bus system, however, the fewer the opportunities for new routes with high load factors, since most of the best routes are already in use. Buses, whose speed is constrained by traffic, can offer little time advantage to most car drivers without dedicated bus lanes. Train systems, including subway and dedicated light rail lines, are expensive to expand, but can offer new connections between locations at relatively high speed. However, new fixed rail systems are often difficult to justify in areas without high population densities or without at least a coordinated plan to encourage growth around new stations.

Among the innovative developments in transit are dedicated busways, which isolate buses from other traffic to increase their speeds and reduce travel times to levels equal or superior to private vehicles. The most famous example of such a system is in Curitiba, Brazil. Several IEA countries have cities with limited busway systems; many have dedicated bus lanes, separated from other traffic lanes by road markings or low physical barrier. Even without dedicated bus lanes, bus speeds can be increased in other ways. One approach is to give buses priority for crossing at intersections, using a system of transponders that triggers traffic signals to *go green* early or *hold green* longer when it senses that a bus is approaching.

Other bus system changes that offer immediate benefits include reducing prices and improving service by providing riders with better information and more comfortable stations. Improved access to stations for pedestrians and bicycle riders, and more nearby secure parking for bicycles and cars, especially in suburban train stations, can also provide immediate increases in ridership.

Paratransit systems have also emerged in many places. *Paratransit* sometimes refers to unauthorized, privately operated vehicles, but can also mean government-operated or authorized systems with vehicles

Transit Initiatives in Los Angeles, California

In Los Angeles, residents take about 1 million bus rides a day on city buses, but that number has not risen significantly in recent years.

In June 2000, the city began a demonstration program to change that, unveiling one of the most advanced demonstration bus systems in the United States. The Metro Rapid program is a complex system based on a simple principle: The faster a bus goes, the more people will ride it. The program employs transponders, remote electronic sensors, video cameras and a computerized control center. Every Metro Rapid bus is equipped with a transponder on the bottom of the vehicle. As the bus runs its route, it passes over sensors in the pavement. If a bus approaches a traffic signal too slowly or quickly to make the green light, the computer delays the green light or shortens the red light by as much as ten seconds to let the vehicle pass. The transponder system also allows all bus positions to be monitored via satellite at an operations control center. It allows for "load balancing" to minimize bus bunching.

Buses in the Metro Rapid program are generally express buses with stops every 0.8 to 1.0 miles, primarily at major destinations and transfer points. The red-and-white Metro Rapid buses are low-floor compressed natural gas vehicles, and have a special exterior paint scheme that is coordinated with the station design. The demonstration program, which involves 100 buses on two bus corridors – costing USD 8 million to USD 10 million – is funded through 2001. During the year, the city will determine whether it should be continued and expanded to more corridors.

Source: http://www.fta.dot.gov/brt/projects/losangeles.html that are flexible in their scheduling and route choices. On-demand transit systems allow commuters and other travelers to reserve transit service for a particular destination or time. Such systems promise to be more competitive with private vehicles in terms of travel attributes important to consumers, such as comfort, travel times, and flexibility. However, paratransit systems usually use relatively small transit vehicles (such as 12 or 15 seat vans), and even then can suffer from low load factors. In some cases they may not be more fuel-efficient, per person, than private vehicles (HBC 1999).

CO_2 Reduction Estimates

Recent efforts to model the systemic effects of transit enhancements on emissions of CO_2 include the European Commission Auto-Oil II modeling program for Athens. The modelers assessed the effect of a package of measures to *improve public transport*, primarily by increasing average bus speeds by 15%. The measures included adding new bus lanes and giving buses priority at intersections. As a result, CO_2 emissions declined for the city's transportation system, but by only a net 0.3%, mainly because of a projected increase in overall traffic congestion due to loss of lanes for private vehicles. The model also assessed the effect of a policy to reduce public transport fares by 30%, which cut CO_2 emissions by 1%. This resulted from an increase in bus ridership of 15% and in rail ridership of 13%, and a 3% decline in car travel (European Commission 2000). A similar modeling exercise undertaken by NOVEM, the Dutch Environment Agency, found that a scenario to *improve public transport* cut CO_2 emissions by a similarly small percentage, 0.5%, for the Dutch transportation system between 1990 and 2010 (as cited in OECD 1996).

These models, while detailed, do not capture all of the impacts of transit improvements, and exclude potential long-term effects on land use. A pro-transit strategy, therefore, might yield much greater-than-estimated reductions in CO_2 emissions in the long term. Some studies have estimated a long-run land-use *multiplier* of five to ten times the amount of the short-run reductions. This effect may be especially strong when transit improvements or expansion are planned in conjunction with land-use decisions and other policies that promote transit use. The last section in this chapter discusses the possible effects of such a package of measures on CO_2 emissions.

Policy Example: Subsidizing a Reduction in Transit Fares

The starting point is the European Auto-Oil II model for Athens, which showed a 1% reduction in emissions of CO_2 resulting from a 30% drop in transit fares. A similar relationship is assumed to hold for most IEA cities, taking into account that the impact may not be as great in areas where many residents live outside the range of urban transit systems. If a national government provides (or increases) transit subsidies in all cities and towns so that fares can be cut by 30%, and the policy affects about half of the country, then national emissions of CO_2 would decline by 0.5%. Given the uncertainties and country-by-country variations, however, reductions between zero and 1% appear reasonable through 2010, perhaps reaching 2% by 2020 after taking into account longer-term impacts on traffic and land use.

Travel Pricing Mechanisms

This section covers a variety of pricing mechanisms to encourage reductions in private vehicle travel and shifts to other modes of travel: roadway pricing (tolls, toll rings, and cordon pricing), annual registration fees based on travel distance, and *pay-at-the-pump* fees. One cost-based measure not discussed is fuel taxes, since a principal objective of this book is to offer policy *alternatives* to increases in fuel taxes. However, the effects of *pay-at-the-pump* programs are similar to those of increased fuel taxes of the same magnitude. This section also does not include parking pricing, which is included in the section on parking-related measures.

All of these measures change the variable costs of driving either per kilometer, per liter of fuel use, or per trip. In some cases they shift fixed costs to variable costs without raising total costs to the average traveler. Such variable costs include parking costs, fuel costs, and roadway usage fees that amount to a toll for each unit of distance traveled. Annual vehicle registration fees are arguably less variable than costs paid per kilometer or at each refueling, but they are certainly more variable than the cost paid, for example, for the purchase of the vehicle. The one-time *point of purchase* cost represents a high percentage of the costs associated with owning and operating a vehicle. Such fixed costs are not likely to enter into the decision about whether to take a particular trip. By shifting some of these fixed costs to variable, paid each time the car is used, a much stronger signal could be sent to drivers regarding the real costs of each trip. This in turn may encourage reductions in vehicle use and shifts to car pools and to other modes of transportation. If pricing is implemented for travel on specific routes, at specific times, it may reduce vehicle travel in a very targeted manner, with some drivers choosing simply to switch the route or time of particular trips. Such a targeted approach may be very useful for reducing congestion and eliminating traffic bottlenecks.

Roadway Pricing

The use of roadway pricing – charging drivers a fee on a roadway or roadway system for each kilometer of travel – can reduce total travel and displace travel to other times or routes. In theory, charging prices throughout the system according to current congestion levels could yield a completely smooth-flowing roadway system. One of the major additional benefits of this approach, as with most market-based allocation systems, is that high-value trips (such as getting to an important meeting on time) can be made during high-cost times and on high-cost routes, and relatively low-value or more flexible trips (such as picking up a few groceries), can be made at other times or using other routes. Thus, individuals determine the value of their trip and decide how much they are willing to pay for it.

While such an approach has long been discussed by economists and some planners, devising a workable system has not, until recently, been

Estimating the Effect of Price Changes on Travel Levels and Fuel Consumption

Since this and following sections cover price mechanisms, it is useful to consider how changes in the cost of travel affect travel levels. Studies show that travel patterns are fairly unresponsive to changes in the fixed or even variable cost of travel. Elasticity studies that look at changes in travel related to changes in fuel cost per kilometer usually estimate short-run travel elasticities between –0.1 and –0.3 (see review in paper by Greene et al. 1999). That is, a 10% increase in the per-kilometer cost of fuel is estimated to yield about a 1% to 3% reduction in travel. Why is this travel elasticity so low? One reason may be that fuel costs are usually a low percentage of travel costs. This may be especially true in countries like the United States that have low fuel prices. Fuel costs are usually around half of variable travel cost, with parking, tolls, and vehicle maintenance taking up the remainder.

Estimates of the elasticity impacts of other variable costs, such as parking and road pricing, are scarce, but these elasticities are related to the share of total travel cost that they represent. If parking costs on a per-kilometer basis are similar to fuel costs (which is true for some drivers in some cities), the impact of a change in parking costs may be close to that for a similar percentage change in fuel costs.

Changes in fuel costs can also affect the types of vehicles people buy, and encourage purchases of more efficient vehicles. Because it affects both travel and fuel economy, fuel cost changes result in greater impacts to fuel use, over the long term, than pricing measures that affect only travel (such as road pricing). Long-term fuel consumption elasticities with respect to changes in fuel prices in recent studies are generally estimated between –0.5 and –1.0 (see review by Dahl 1995).

The impacts of various price changes on emissions of CO_2 are similar to fuel use, since these emissions are closely correlated with fuel use.

possible. Road tolls historically have been collected manually at tollbooths, which are hardly efficient: in many cases the booths themselves have been sources of congestion for drivers. Their use has usually been justified as a way to raise revenue for roadway maintenance or construction. In some cases tollbooths have been removed once the capital costs of a roadway project have been covered. This revenue approach is quite different from the notion of treating the roadway as a resource, and charging in order to efficiently allocate it.

Recent technologies, however, have opened up new possibilities. Systems using remote sensing of vehicles and automatic vehicle identification can automate toll revenue collection, do not require vehicles to stop, and have lower operational costs than traditional tollbooths. They can allow toll rates to be updated frequently to reflect congestion levels or the occurrence of accidents. Systems for setting toll rates can reflect various policy objectives, such as not charging high occupancy vehicles in dedicated lanes. The electronic transponder mounted on each vehicle usually carries a code unique to the vehicle or driver. This transponder may be no bigger than a credit card and is generally mounted on the windshield. With such technology, drivers can pay tolls electronically at highway speeds, eliminating the congestion caused by conventional toll plazas.

Public Support for Roadway Pricing

Despite the development of new technologies that allow innovative approaches to roadway pricing, most initiatives have not been successful due to lack of public support. The few projects that have been successful have applied tolls in order to finance new roads. Such toll roads often set rates to recover costs, which may be considerably lower than a level set to eliminate congestion or substantially reduce travel demand. Congestion pricing initiatives are often opposed by automobile associations and consumer and business advocates, for reasons that include:

- Negative views toward paying more for driving, especially on existing roads that have traditionally been viewed as *free*.

- Concerns about equity, as road pricing is regressive and disproportionately affects lower-income drivers, who may have less choice in determining the timing of their trips and thus would have no option but to pay the fees.
- Privacy issues associated with electronic tolling technologies, as they can identify the time and location of vehicles crossing pricing points. (These issues can be overcome using pre-paid anonymous debit card systems, with the card in the vehicle debited at each toll, rather than maintaining individual accounts on a central computer).
- Adverse economic effects on areas subject to roadway pricing. Pricing systems around a downtown or other area could be seen to conflict with strategies to encourage commercial activity and employment in these areas, though whether they actually do so is still being debated.
- Lack of alternatives to car travel, such as adequate mass transit.
- Inability to price a sufficiently high percentage of roadways to reduce overall travel, so that vehicles simply shift from one roadway to another.

To win support, it appears important to show that roadway pricing will in fact reduce congestion and to earmark revenue for road maintenance and travel alternatives. Roadway pricing that involves variations on the basic approach of charging for the use of individual corridors also has had some success.

Toll Rings and Cordon Pricing

In theory, the greater the percentage of roadways covered by road pricing, the more efficient the system is likely to be, since the opportunities are fewer for vehicles to shift to other nearby, unpriced roads. Setting up a comprehensive system of pricing for all roads in a region, or even for all limited-access roadways, has proven very difficult. But one step in this direction that appears viable is the establishment of a *toll ring* around a city or central business district. Toll rings apply

Congestion Pricing: Ontario Highway 407

Congestion pricing has been implemented in Canada on Ontario's Highway 407 Express Toll Route near Toronto. This expressway was opened in 1997 and is the first all-electronic, open road toll highway in the world (ETR 2000).

The toll system works as follows: for light-duty vehicles, daytime rates are USD 0.10 per km during peak periods from 5:30-9:30 a.m. and 4-7 p.m. weekdays, USD 0.07 per km off-peak, and USD 0.04 per km at night from 11 p.m. to 5:30 a.m. Drivers never have to slow or stop to pay tolls. When a vehicle enters one of the 28 highway interchanges, it drives under an overhead tolling frame, called a gantry, which automatically records the beginning of the trip. When exiting the highway under another gantry, the electronic sensors record the exit. Drivers can apply for a transponder, a small electronic device that attaches to the interior windshield of the car and logs each vehicle onto and off the system. For highway users who do not have a transponder, tolls are tallied using a state-of-the-art license plate recognition system that sends a video image to a central processing computer of the vehicle entering and exiting the highway. An invoice is sent by mail. Additional charges are levied for drivers without a transponder (USD 1.00 per trip and USD 2.00 for each 30-day period they drive on the highway). Transponder users are charged a USD 2.00 account fee every month whether or not they use the highway.

As of 1999, the average weekday number of trips was about 250 000 and rising. Annual revenue from the roadway is expected to reach USD 100 million by 2000. Thirty percent is used to pay the operating expenses of the roadway, and the remainder is used to amortize the construction cost. The operating company estimates time savings of around USD 140 million per year for drivers in the Toronto area.

a charge to vehicles entering most or all of the access points into a city. In effect, all roads within the ring carry a charge for those vehicles entering from outside, although it is a charge per entry, not a charge per vehicle kilometer. By increasing the cost to enter the ringed area, toll rings can reduce the average number of vehicles inside the area and, at their best, effectively eliminate traffic congestion within the area. Charges can be raised during peak travel times (i.e., congestion-priced) to encourage commuters to choose carpools or transit into the city. Singapore has perhaps the most famous toll ring, which is part of a broad package of aggressive measures to limit car ownership and use on the island. Norway may have the most toll rings of any country, with one around each of their three biggest cities (see box).

Toll rings appear to work best for areas with a limited number of access points, such as islands and cities surrounded by natural barriers such as rivers and mountains, or man-made barriers such as peripheral highways. Toll rings may also work well for cities, like many in Europe, which have historically limited access to the central city through city gates. While toll rings are thought by some to discourage businesses from locating in the cities they enclose, there is no evidence of such a problem in cities like Singapore and Oslo. However, in Oslo, the cost of entry is not high enough to discourage most commuters from continuing to enter the city by car.

Toll rings are an example of cordon pricing, which is a zoned pricing system. In any cordon-pricing system, cities or regions are divided into multiple zones and vehicles are charged a fee each time they cross a boundary into a different zone. Thus toll rings are cordon-pricing systems with two zones. Multi-zone cordon systems have been shown to be technically feasible, using transponders built into the roadbed and units in vehicles for identification and/or billing purposes. Multi-zone systems represent a compromise between a simple two-zone toll ring system and a complex system to charge drivers for every kilometer traveled on all roads within a city. Multi-zone cordon systems have been proposed for a number of cities, but none are known to have been implemented.

Toll Ring Pricing in Norway

The Norwegian experience in developing toll rings around major cities is regarded as one of the most successful road pricing efforts worldwide. There are toll rings operating around each of the three largest cities in Norway: Oslo, Bergen, and Trondheim. All were implemented in the late 1980s and early 1990s. Each system has since adopted new technologies or has been expanded.

The Norwegian public has come to accept tolling over the years as necessary to fund new highway infrastructure. Due to the rugged geography, particularly on the coast, it is expensive to build new roadways, bridges, and tunnels. Thus, when the concept of toll rings was introduced in the 1980s, it did not face the degree of opposition that would be expected in other countries.

The ring tolls in Trondheim are levied at 12 plazas that control all entry points into the central area, where 40 000 of the region's 250 000 people reside. Many of the main businesses and institutions, and the harbor, are within the ring. The system is nearly fully automated and most of the toll plazas are unmanned. Ninety percent of vehicles have electronic transponders, which allow them to pass through the gates at highway speed while their entry is read and debited by a central computer. Other occasional users pay via a coin machine or card-reading machine at gated lanes.

The entry cost varies by time of day from around USD 0.60 per entry off peak to USD 1.20 during peak times. Users are charged a maximum of one entry per hour (subsequent entries are free) and 75 entries per month, so that people who live close to the ring or who must travel frequently do not have huge toll bills. No tolls are charged from 6 p.m.-5 a.m. or during weekends. Vehicles over 3.5 tons pay double.

Surveys indicate that drivers have changed travel patterns as a result of the system. According to a 1991 survey of commuters, nearly half reported that they had adjusted their travel patterns in some way as a result of the toll rings and a significant percentage had switched to transit. (EURONET / ICLEI 1998).

Most analyses of road pricing and toll rings have not looked at their effects on fuel use or emissions. Indeed, most have not conclusively shown a net reduction in regional travel. One difficulty in undertaking such an analysis is that many road pricing projects have been part of the construction of a new roadway or additional lanes. It is difficult to isolate the effect of such a pricing project, since the new roadway may contribute to an overall increase in travel, though the roadway pricing dampens this effect.

Some modeling studies have attempted to isolate the effect of pricing. The European Commission's Auto-Oil II Program modeling effort (EC 1999) analyzed the effects on fuel use and CO_2 emissions of a hypothetical road-pricing system for Athens and Lyon. This involved a cordon-pricing system with multiple zones throughout the metropolitan area with an average per-kilometer charge of about USD 0.25 during peak times and USD 0.05 off-peak. These charges are higher than fees discussed elsewhere in this chapter – for a driver who travels mostly at peak times, they could amount to several thousand US dollars per year. In this modeling exercise, these charges increased average *generalized* travel costs (which include all variable *out-of-pocket* costs and time cost) for cars by about 16% per trip. In contrast, per-trip generalized costs for buses dropped 2% due to lower congestion levels.

As a result of the higher per-trip costs, car travel declined about 14% in the modeling for Athens, slightly less in Lyon. About half of the reduction in car travel was shifted to transit, and the other half was shifted to non-motorized modes of transportation or avoided completely. Some car travel also shifted from peak to non-peak periods of less congestion. As a result of these travel shifts, CO_2 emissions in both Athens and Lyon declined significantly, by 8%-10%.

Less spectacular results from a road pricing policy should be expected in regions that are more dependent on cars, since drivers will have fewer options for avoiding the fees. But given the extensive coverage of cordon pricing, fuel savings and CO_2 reductions should be significant wherever it can be implemented with a fee that approximates an average per-kilometer fee of about USD 0.25.

Converting High-occupancy Vehicle Lanes to High-occupancy Toll Lanes

High-occupancy vehicle (HOV) lanes are designed to encourage increased numbers of passengers per vehicle and, therefore, reduce the number of vehicles on the road. They usually do this by restricting access to highways to those vehicles meeting the minimum occupant requirement, usually two or three riders per vehicle. These are found in many countries around the world, but are especially popular in the United States. A major question with HOV systems is whether they reduce total vehicle travel and emissions. The direct effects of HOV lanes are clear enough – congestion-free travel for participants and relatively efficient vehicles (per passenger kilometer). However, a number of secondary effects could offset these benefits, including increased travel by vehicles picking up other passengers to become HOV, and increased travel by non-HOV vehicles that choose to remain single-occupant vehicles, for example, by taking alternative routes that may be longer or involve more stop-and-go driving.

Fielding and Klein, 1993, identified three shortcomings of HOV lanes in the United States. Many HOV facilities are underutilized, even though nearby roadway systems are highly congested. This may reflect decisions by drivers to ride alone in congested traffic rather than carpool in free-flowing traffic. Second, many car-poolers would probably travel together even without a HOV lane. Fielding and Klein found that 43% of car poolers are members of the same household. They also found that HOV 3 lanes, more than HOV 2 lanes, avoid a large “free rider” problem, but tend to be greatly underutilized. Finally, HOV lanes can be expensive to construct, especially if they require new highway capacity to be built. The authors note that adding HOV lanes to the Santa Ana Freeway in California cost an estimated USD 5 million per lane mile south of Santa Ana, and twice that north of the city.

One way to increase the use of HOV lanes is the addition of roadway pricing. Vehicles not meeting the HOV criteria could pay a toll to ride on lanes. In effect, HOV vehicles are given a discount or free access to tollways. This approach has been termed High Occupancy/Toll lanes, or HOT lanes. Fielding and Klein argue that this not only increases the efficiency of HOV lanes, but also might be a more acceptable or even popular way to introduce road pricing. They describe an approach whereby underutilized HOV lanes are adapted for electronic tolling, so none of the speed benefit of the lane is lost, and then eventually other lanes are adapted. HOV vehicles could continue to travel free of charge on all tolled lanes.

Converting a HOV lane to a HOT lane is not technically difficult. The technology described in this report for non-stop electronic toll collection, using windshield-mounted transponder tags, obviates the need for tollbooths. HOT lanes can be separated from regular lanes by pavement striping and low-cost lane separators, such as anchored plastic pylons.

While converting vehicle lanes to HOV lanes usually represents a major (and often politically difficult) initiative, converting existing HOV lanes to HOT lanes may be easier. Such conversion might not reduce CO_2 emissions immediately since it would effectively increase roadway capacity and could reduce average vehicle occupancy levels. Rather, conversion of HOV into HOT lanes could represent an important step towards building public acceptance of electronic tolling and congestion pricing.

Vehicle Registration Fees

Registration fees are an annual payment that can be levied at the national, regional, or local level. In most countries they are too low to affect travel. They usually represent a fixed fee per vehicle, and are not linked with vehicle fuel economy or travel. However, registration rates that are based on engine size, which correlates with fuel economy, are common in Europe; countries such as Denmark are beginning to introduce fees based on rated fuel economy (see Chapter 2).

HOT Lanes in California

More and more High Occupancy/Toll lanes are being created in the United States. As of 2000, the country had four operational HOT lane facilities and 20 more in the planning or development stage. One example of a HOT lane system is Highway SR-91 in Southern California. In this case, four HOT lanes were built in the median strip of the existing highway, and introduced from the beginning as a combination of High Occupancy Vehicle lanes for a minimum of three passengers and electronic toll lanes for other vehicles. The lanes were built by a private company, which plans to recover its costs through the tolls collected. Toll rates vary by time of day and can be adjusted to ensure non-congested travel conditions at all times. The lanes on SR-91, completed in 1995, are generally considered a success, both in terms of their levels of use and revenue. Average speeds on the tolled lanes are higher than those on the free lanes, but average speeds on both sets of lanes are much greater than on other nearby highways. Surveys indicate that while a diverse group of motorists use the toll lanes occasionally; relatively few use them all the time. This indicates that the HOT lanes are not used exclusively by a select group of wealthy motorists, but occasionally by all motorists when the value of reducing trip times warrants paying for access to faster lanes or travelling as a group of three or more.

Sources: Sullivan 1998, Poole and Orski 1999.

As annual vehicle registration fees are usually a fixed annual cost, they are not likely to affect travel. They might, however, if that cost were more variable, for instance, if registration fees were based on travel or fuel use, which can be calculated by multiplying the number of kilometers traveled by the vehicle's rated fuel economy. Still, it is unclear how much any annual payment would affect travel behavior over the course of a year.

One difficulty with travel-based registration fees is calculating the amount of annual travel. Travel is usually self-reported on the registration application, but could be checked by a third party, for example as part of an inspection and maintenance program. It is technically possible for a central computer to automatically record the travel of cars outfitted with transponders, but may not be politically feasible because of concerns about privacy. If such a system is feasible, however, registration fees can be automatically billed or deducted from bank accounts, and assessed more frequently. If fees are collected monthly, such an approach could tie travel much more closely to the fee and send a much clearer price signal to drivers.

Another concern is that very high registration fees may be needed to reduce travel or dampen its growth. For example, a fee of USD 0.05 per vehicle kilometer driven may not be high enough to encourage many people to change their driving habits. For a person who drives 15 000 kilometers per year, this fee would amount to USD 750, rivaling gasoline costs in some countries. Shifting to a monthly system of payment could avoid the “sticker shock” of having to pay one large sum. Another approach to improve the political viability of travel-based fees is to offer drivers a base level of kilometers above which fees are applied or below which lower fees are applied. This might work particularly well with a monthly billing system – drivers would have a monthly allotment of kilometers to budget.

Policy Example: Cordon Pricing

Based on the analysis developed by the European Commission using their Auto-Oil II model, a policy example has been developed for a national incentive to implement cordon pricing in all major metropolitan areas of a country. This incentive could be a promise of national funding support to help develop the system. If areas covering 50% of national vehicle travel adopt cordon pricing, with a peak rate of USD 0.25 and off-peak rate of USD 0.05 per kilometer, reductions in CO_2 emissions should total half the amounts estimated by the study – between 3% and 6%. The reductions may be greater in the long term as people and businesses make decisions about land use and location that take into account the higher cost of travel.

Pay-at-the-pump Fees

Pay-at-the-pump fees are payments for driving-related services that are included in the cost of fuel, and are paid each time one fills up at the gas pump. Such an approach to fee collection could be an excellent approach to saving oil and reducing CO_2 because, like fuel tax increases, it encourages both reductions in travel and increases in fuel economy. In the case of *pay-at-the-pump* fees, fuel costs can be raised without necessarily raising average travel costs to motorists. This is because most fees usually considered for payment at the pump are costs already borne by motorists, but paid separately. They are often fixed fees, such as vehicle registration, which if converted to a fee paid during each refueling would become a variable fee. In fact, gasoline taxes that are earmarked for roadway maintenance are an example of this – a driving-related cost that is collected during each refueling. Analysts in the United States have looked into pay-at-the-pump as a means to reform drivers' insurance, offering a means to collect insurance fees from all drivers, even those who illegally have not purchased insurance policies.

The United States Department of Energy (US DOE 1995) pointed out that, although pay-at-the-pump fees are often linked with insurance reform, this does not have to be the case. Revenues from pay-at-the-pump policies can complement current insurance systems to create revenue pools that cover the costs associated with uninsured motorists and to fund premium rebates to insured drivers. A number of other driving-related costs could be shifted, in all or part, to a variable cost paid at the time of refueling. These include vehicle registration fees, and vehicle inspection and maintenance fees that could fund all inspections and required repairs. Even costs associated with providing emergency services to drivers (such as towing, policing and ambulances) could be shifted, at least in part, to the pump.

Pay-at-the-pump programs would provide powerful signals to drivers not only about their amount of travel but about their choice of vehicle, as payments would be based on fuel consumption. As the effect of pay-at-the-pump policies are similar to fuel tax increases, it is reasonable to expect similar travel and fuel consumption elasticities. These signals, however, may not correspond with other social objectives, such as equity or maximizing vehicle and travel safety. For example, it may be considered unfair that drivers with the most fuel consumption would pay the most, since some drivers might use a lot of fuel per kilometer but have good driving records. Therefore, it is generally believed that only a small portion of costs like insurance can be converted to the pump without loss of political support.

Policy Example: Special-Purpose Tax on Fuel Purchases

This example examines a national program that uses revenue from a new tax on fuel purchases to cover certain, previously fixed costs like part or all of auto insurance premiums, vehicle registration fees, vehicle inspection and maintenance programs, etc. A critical component of such a policy is tying the new fee to reductions in the previous charges for the services it covers. If the new fee represents a 5% increase in fuel prices (e.g. USD 0.05 per liter on a price of USD 1.00 per liter), vehicle-kilometers traveled, fuel consumption and CO_2 emissions would decline by 1% in the first one to two years, and by 2%-4% by 2010 as consumers purchase more fuel-efficient vehicles. The impacts would increase through 2020, with reductions in fuel use and CO_2 of 3%-5% by then, as the new, more efficient vehicles dominate the vehicle stock.

Parking-related Measures

Parking pricing and related measures, which include raising the cost of parking, restricting its supply, improving enforcement of existing laws, or encouraging employers to provide incentives to their employees who do not park, can be a powerful means to discourage private vehicle driving and to promote alternative modes of travel.

Parking Pricing and Enforcement

Raising the cost of parking is another approach to increasing the variable cost of driving. Some cities, where most parking already carries a cost, can simply raise parking rates (at least for public parking spaces) or improve enforcement. Other cities, such as many in North America, where free parking has long been plentiful, may have to first gain support for implementing basic charges for all parking. Governments can increase the price of parking by:

- Raising rates at public parking facilities or metered spaces.
- Increasing taxes on private parking facilities, which is likely to lead to an increase in the retail price of parking.
- Developing more restrictive regulations regarding the provision of parking spaces in new buildings.
- Tightening enforcement of parking regulations or increasing fines for parking violations.

Parking policies can be designed to target certain groups or types of vehicles. For example, single occupant vehicles, or commuters, or both, can be targeted by raising parking prices during peak hours, offering parking discounts for car or van pools, raising rates substantially after a parking duration of more than one or two hours, and prohibiting discounts for long-term parking.

For many cities, better enforcement of existing parking laws may be the most practical way to increase the effective cost of parking and reduce demand for parking, and therefore of vehicle use. Lax enforcement tends to reduce or eliminate price signals that would otherwise be sent by carefully planned parking restrictions.

Development of "Parking Benefit Districts"

Parking pricing may be absent, and/or enforcement may be lax, in part because neither is politically popular with residents. Why is this so? Shoup (Shoup 1995) points out that part of the reason is that parking revenues (and revenues from parking-related fines) are often put into a locality's general fund, or even used to fund car-related infrastructure such as off-street parking lots. Therefore, area residents may perceive few benefits from restricting parking supply or pricing it – only costs. Shoup proposes *Parking Benefit Districts*, small, neighborhood-sized areas that receive revenues from local parking charges and can allocate them for neighborhood improvement projects such as sidewalk and street repair, tree planting and trimming, street cleaning, graffiti removal, historic preservation, or burying overhead utility wires. Associating parking revenues and fines with tangible neighborhood improvements may be a powerful means to increase local support for paid parking, stricter parking regulations, and better enforcement.

Restricting Parking Supply

Many cities and some regions, particularly in Europe, restrict the supply of parking to discourage driving. In contrast, many other cities, particularly in North America, have zoning regulations that specify a minimum, rather than maximum, number of parking spaces according to the number of workers or floor space per building.

Research on such minimum parking requirements indicates that minimum levels may be unnecessarily high and actually encourage driving. Willson (Willson 1995) points out that minimum parking requirements can create a vicious circle: if the required number of spaces is set so high that it guarantees a space for all potential vehicles, even at peak times, then it tends to push the market price of parking toward zero, which in turn triggers demand for parking that approaches this very high level of supply, making it appear necessary. Shoup (Shoup 1997b) indicates that minimum parking requirements in the United States are based more on historic precedent than on evidence about the true level of parking needed in a particular building. By 1993, 54% of the cities in the United States that Shoup surveyed required four off-street spaces to be provided per 1 000 square feet of office space, up from 27% of cities with that requirement in 1973. By the early 1990s, the minimum parking requirement was an average of 3.8 spaces. Since one parking place uses 300-350 square feet, parking requirements in the United States usually result in more area allotted to parking than to office space itself.

Shoup estimates that the number of parking spaces could be reduced by as much as 25% for most buildings, to around 3 per 1 000 square feet, and still provide enough spaces for all drivers on all but the busiest days of the year. In cases where drivers pay modest prices for the spaces, Shoup estimates that the requirement could be dropped to as low as 2.4 spaces per 1 000 square feet, allowing the total area devoted to parking to be cut almost in half. This in turn could allow denser, more pedestrian-friendly development. Shoup's estimates suggest that localities should reconsider minimum parking requirements.

Examples of Aggressive Parking Policies: Bern, The Hague, and Ghent

- *Bern, Switzerland, has only 6 000 parking spaces for 60 000 workers in the city center. The number of spaces in the historic district has been cut by more than half since 1960.*
- *The Hague, Netherlands, bases its parking policy on the availability of parking on the street and in employee lots, and on transit accessibility. Zones in the city and region are ranked A, B, and C according to their level of transit. Parking is priced higher in areas with good transit availability, which includes most areas. The zone system also governs the maximum number of parking spaces a company can provide employees. In the A zone (which comprises much of the downtown area), the limit is one space per ten employees. In the B zone, it is one per five employees and in the C zone, one per two.*
- *Ghent, Belgium, has a two-tariff parking pricing system (the "postponed parking tariff") that significantly raises the parking rate for cars parked longer than two hours. This also applies in the form of a mild fine for those who do not pay at all – violators are assumed to have parked for more than two hours and are charged at the half day rate of about USD 9. This relatively low fine system might raise the acceptability of strict enforcement.*

Parking Cash-out

Once a city or region allows the growth of cheap or free parking, charging for it can be politically difficult. An approach called parking *cash-out*, whereby employers offer employees a cash allowance for commuting in lieu of free parking, may be an intermediate step. Governments can encourage businesses to make this offer by taxing them for the number of spaces used by their employees, or offering a tax deduction for money businesses distribute through such a program.

Parking cash-out presents several problems, but each has solutions:

- Enforcing the non-driving of those who choose to take cash and promise not to drive is difficult, as employee parking lots are not usually monitored. A charge per entry could be instituted at employee parking lots; some revenue could go to the employment of a parking lot attendant.
- Those who promise not to drive to work could continue to do so and park in nearby lots or on-street parking. To counteract this, at least in part, municipalities could restrict on-street parking (for example, to residents of the area), or implement a significant charge for on-street parking (metered parking).
- If the perceived value of parking is near zero, due to an abundance of free spaces, employers may be inclined to provide very little cash as an equal-value incentive for employees to stop driving alone to work. Governments could require that the cash-out rate is set high enough to encourage a certain percentage of drivers to stop driving solo. As more firms offer cash-outs, the level necessary to achieve targets becomes established.

Potential CO_2 Reductions from Parking-related Measures

As the parking-related measures discussed in this section tend to increase the per-trip cost of travel, it is reasonable to expect similar travel and fuel consumption elasticities from other types of charges such as road pricing, and similar effects on CO_2 emissions. As with roadway pricing (and unlike gasoline taxes), parking charges are unlikely to affect vehicle choices, so it will reduce fuel use and CO_2 mainly through reductions in vehicle travel, not improvements in fuel economy.

Parking costs as a percentage of travel costs are usually much lower in North America than in Europe, so parking prices there would need to be increased by a higher percentage in order to reduce travel significantly. In any country or city, increases in effective parking costs can be achieved a number of ways, such as through improved enforcement, restricting parking supply, and cash-out programs. Such measures may be more politically acceptable than an outright increase in parking prices.

Policy Example: National Tax on Parking

Since parking costs vary greatly from locale to locale, one measure that could be applied by national governments is a new national tax on parking spaces. This tax must be passed onto drivers in the form of daily or even hourly parking charges. A program to "cash out" the parking space could be offered as an alternative. Some or all of the revenue generated from the new tax could be returned to localities for increased enforcement of all parking, public and private. If the tax is USD 3.00 per space per day, and half of all cars park for two hours or less and the other half park all day, per-trip costs would rise an average USD 2.00. Travel and CO_2 emissions would decline 7%-14% in areas subject to the tax. (The rise in per-trip costs is similar to that in the policy example for roadway pricing, but yields a slightly greater reduction in travel and emissions of CO_2 since the tax cannot be avoided by driving at off-peak times.) If this policy could be implemented and enforced effectively over half of any given country (assuming that enforcement would be difficult in rural and some suburban areas), then national travel, fuel use, and CO_2 emissions would fall a net 4%-7%. This reduction might increase over time as people, businesses and localities factor the tax into decisions about location and land use.

Land-use Planning and Non-motorized Modes

How can land-use planning be used to promote non-motorized forms of transportation such as walking and bicycling? The longer-term potential benefits of planning are considered, such as those resulting from modifications to zoning regulations, followed by planning options that may have more immediate effects, like improvements to the existing transportation infrastructure.

Long-term Land-use Planning

Changes in land-use planning aimed at the spatial structure might not achieve measurable reductions in fuel use or CO_2 by 2010, but that does not mean these changes are unimportant. Changes in land use now may hold the greatest potential for reductions of CO_2 emissions of any type of measure to reduce travel, over the long term. Land use is important because every trip depends on calculations by a traveler about how to reach a destination quickly, comfortably, and cheaply.

In virtually all IEA countries, changes in land use are creating a greater dependence on vehicle travel, not less. New developments tend to be single use rather than mixed-use (housing, office space and retail). These are usually of medium or low density, built on previously undeveloped land, far from urban centers or even other developments. Housing is often placed beyond walking distance from offices, shops and even schools.

Changes to land-use planning that reduce dependence on vehicles could start to affect housing stock, travel and emissions in the medium term. Dwellings constructed over the next ten years will comprise 10% or more of the total housing stock in many countries. As shown in Table 3.1, housing built between 1990 and 1995-1996 in selected IEA countries accounts for 3%-11% of total housing. Housing built since 1980 accounts for more than a quarter of the total stock in some countries. However, estimating the potential fuel savings and CO_2 reduction that can be achieved through specific changes in land use is very difficult; the issue is complex and poorly understood.

Table 3.1

Housing Stock Turnover in Selected IEA Countries

Country	Year of data	Percent of total dwellings built since 1990	Percent of total dwellings built since 1980
Denmark	1996	4.0	13.8
France	1996	5.7	15.1
Ireland	1995	10.9	27.6
Netherlands	1996	8.4	26.9
United Kingdom	1996	3.3	12.0
United States	1995	6.5	22.1

Source: UNECE 1998.

Short-term Planning – Promoting Non-motorized Modes

Changes to the existing transportation infrastructure could, in the short term, encourage a shift towards *non-motorized modes*, increasingly called *active transport*. These forms of transportation, which usually involve active movement by travelers, i.e., walking, bicycling and even rollerblading, use no fuel and produce no CO_2 emissions. Changes can be adopted that encourage people to take entire trips or partial trips with non-motorized modes that link with mass transit. Clearly, enhancements to the pedestrian and bicycling environment can be part of a broader strategy to promote livability, that is, to make community space and city streets safer and more attractive, lively, and interesting.

Bicycle use is so low in many countries that even a large percentage increase will not substantially offset vehicle travel. Bicycling accounts for a negligible percentage of total passenger kilometers of travel in most IEA countries, although as a share of total trips it reaches 10% or more in several European countries like the Netherlands, Denmark, Sweden, Germany, and Belgium. In Denmark and the Netherlands, people bike an average of over 800 km per year, compared with less than 350 km in all other European Union countries.

Walking represents an important but generally declining mode, especially in Europe. Walking and cycling together account for more than 10% of total work trips (but not kilometers) in many European cities, and as much as 30% in cities like Copenhagen and Amsterdam. However, as a percentage of all travel (including work and other travel), these modes account for an average of only about 5% for the European Union (European Union data, 2000).

Cities with high levels of bicycling, such as Copenhagen and Amsterdam, are special cases: both have flat terrain and an historically strong bicycling tradition. It is unclear whether other cities can increase bicycle ridership to similar levels, but they could develop similar bicycle infrastructures, with a network of bike lanes and structures for parking bicycles, and more strongly enforce traffic laws, which would increase safety for bicyclists.

Measures to Promote Non-motorised Transport

Measures to promote bicycling and walking include *carrot* measures such as improving pedestrian and bicycling infrastructure, and *stick* measures like reducing the attractiveness of car travel. Some measures, such as narrowing streets and increasing the width of sidewalks, do both. Hagler Bailly Canada (HBC 1999) categorizes enhancements to the pedestrian environment as follows:

- New and/or widened sidewalks that are adjacent to the curb or separated from it.
- More clearly marked crosswalks, with overhead traffic signs for mid-block crosswalks.
- Signalized intersections.
- Grade-separated pedestrian connections.
- Improved street lighting.
- Call boxes to be used to contact emergency services.
- Appropriate signage and/or directional indicators for all pedestrians, including those who have impaired sight or hearing.

At least two studies have shown that improving the pedestrian environment yields a decline in vehicle travel. Portland's LUTRAQ (Land

Promoting the "Urban Village" Concept in Victoria, Australia

In 1995, the state government of Victoria (including Energy Victoria, the Environment Protection Authority, and the Department of Infrastructure) and various local governments developed an "urban village" concept and collaborated on eight studies to explore the feasibility of applying it in eight local areas, primarily around the capital city of Melbourne. The concept of the urban village, as adopted in Victoria, includes revitalizing urban centers through the redevelopment of existing areas, and emphasizing pedestrian friendly, mixed-use developments.

Concept plans were developed for several communities. Work began in the late 1990s on coordinating development in selected areas. As of 2000, significant progress has been reported in a number of communities. For example, East Brunswick, one of Melbourne's inner suburbs, has been identified, studied, and planned as an Urban Village. The project there focuses on redeveloping key areas and building in mixed-use developments, while capitalizing on existing features of the area such as a tram terminus and open space along creeks. The project integrates increased traffic-management through restrictions and traffic calming techniques, and car parking in special access lanes behind new homes rather than on the streets in front. New housing construction focuses on an energy-efficient style of town home (Victoria 2001).

Use-Transportation-Air Quality) series of studies developed a *pedestrian environment factor* (PEF) to rank ease of street crossing, sidewalk continuity, street connectivity, and topography. Their statistical analysis indicated that each unit increase in PEF corresponded to a reduction in daily vehicle miles traveled per household of 0.7, or slightly more than 1 km (Parsons 1993). Similarly, the Maryland National Capital Parks and Planning Commission (M-NCPPC) has shown that the condition of pedestrian and bicycle infrastructure is important in decisions by commuters regarding their choice of mode of transport. However, the specific effects on vehicular traffic speeds, and, therefore, fuel efficiency, is unclear. A traffic calming effort in a 610 hectare area of Mainz, Germany, with 15,000 residents found a mixed effect on fuel consumption, from a 5% increase to a 10% decrease, depending on the driver.

The most important measures for increasing bicycle use appear to be the provision of bike lanes or bike paths that are protected, when necessary, from vehicle traffic. Other improvements include:

- Installation of safety devices, such as better lighting and signage.
- Provision of lockers, racks and storage facilities, as well as ancillary facilities such as changing rooms and showers in work locations.

Traffic Calming Programs in Berlin and Mainz

In the late 1980s, Berlin embarked upon a traffic calming program designed to slow traffic to 30 km per hour throughout the city. Streets were narrowed, lined with trees and shrubs, and 4 meter-wide speed tables were placed at intersections. Streets have been transformed from dreary auto thoroughfares into "pleasant avenues which appear spacious and have enough room for numerous purposes" (Keller 1990). Furthermore, drivers were found to drive more slowly, and brake and accelerate less aggressively.

An earlier traffic calming effort, in a 610 hectare area of Mainz, Germany, resulted in:

- *No change in traffic volumes.*
- *A drop in average speed from 37 km per hour to 20 km per hour.*
- *An increase in average trip time from 283 seconds to 316 seconds – an increase of 33 seconds.*
- *Unchanged numbers of less severe accidents, but a 43%-50% drop in fatalities and a 60% drop in injuries.*
- *A decrease in noise by as much as 14 dBa.*
- *Depending on the driver, a 5% increase in fuel consumption to a 10% decrease.*

(Bundesminister für Raumordnung 1979, cited in Davidson 1997).

- Improved interconnectivity with transit.
- Improved accessibility to mass transit, especially allowing bicycles on trains and buses.
- Keeping bikeways clear and operational year-round.
- Developing information and support for bicyclists.

Several obstacles must be overcome in implementing effective strategies to increase bicycling and walking. These include:

- Funding: these projects are usually funded by municipalities, which normally will not consider them unless they have clear benefits. Linking these projects to the vitality of commercial areas, or their funding to transit revenues, are ways to encourage support. For new areas, localities could set development fees high enough to cover the costs of such projects. Businesses might support their own pedestrian-friendly shopping areas.
- Inappropriate existing infrastructure: retrofitting may be unpopular if construction interferes with normal activities. Clearly, efforts to enhance the infrastructure should focus on the most cost-effective projects.
- Conflicts between pedestrians, cyclists, and drivers.
- Inappropriate local weather conditions: areas that experience periods of excessive heat or cold may have to consider creating structures like underground tunnels or enclosed walkways.

Policy Example: Improving the Infrastructure for Non-motorized Travel

Since it is difficult to generalize about the effects of improving the infrastructure for non-motorized travel on vehicle travel and CO_2 emissions, this policy example makes simple assumptions about those effects. This policy involves earmarking a small amount of revenue from fuel taxes (1% or less) for investments in local non-motorized travel, and providing monetary awards for localities that achieve target increases in non-motorized travel. If the target is a 50% increase in non-motorized travel and the incentives are strong enough that 50% of localities undertake and achieve this goal, then non-motorized travel would increase 25% nation-wide over, perhaps, a five-year period. About 80% of the increase in non-motorized travel is assumed to be drawn from private vehicles and transit, with the remaining representing autonomous increases in walking and bicycling. For a country where walking and bicycling accounted for 10% of total travel before the policy came into effect, this share would increase to about 12.5%. The shares for car and transit would decline in turn by about two percentage points, and CO_2 emissions would drop by a similar amount or slightly less. (That is because some trips would shift from vehicles, such as buses, that nonetheless continue to make trips). Since walking and bicycling as a share of total per-kilometer travel is below 10% in most countries (and averages 5% for the European Union), such a policy would reduce fuel use and emissions of CO_2 from near zero to perhaps 3% for a successful program in a country with high starting levels of bicycling and walking. The Netherlands and Denmark could achieve reductions of 5%. However, cities in these countries might have more difficulty in attaining the target increases since they already have strong bicycling and walking infrastructures, and thus few straightforward alternatives for increasing the share of walking and bicycling.

Costs and Other Considerations

The cost of encouraging non-motorized travel can vary widely. Re-striping roadways to add bike lanes is inexpensive compared to building dedicated bikeways. In all cases intangible benefits such as safety, reduce travel times and livability may outweigh the monetary costs, but are very difficult to measure.

Telematics and Telework

Thanks to improvements in telecommunications and telematics[25] over the past decade, more work, especially information-related work, can

25. Telematics refers to using computers in concert with telecommunications systems. This includes dial-up service to the Internet as well as all types of networks that rely on a telecommunications system to transport data.

be done outside traditional offices, without a serious loss of productivity. An increasing pool of workers has the option to work at home some or all of the time, and, therefore reduce the number of commuting trips.

A key question regarding the impact of telework on travel and fuel use is whether there is much of a rebound effect in the form of increased non-commuting travel (such as increased numbers of shopping trips). Most studies of particular telework programs and telework activity in specific cities have found relatively small travel rebound effects. However, the studies have usually ignored or been unable to estimate two potentially important rebound effects: increased relocation of households further away from the workplace as commuting distance becomes less important in choosing locations, and increased travel by others on roadways vacated by telecommuters. One study by the United States Department of Energy (DOE 1995) on the effect of telework on travel accounted for all three types of rebound effect. It found that, in the long term, around half of the travel-related energy savings of telework might be lost to the rebound effects. The study acknowledged that its estimate of the effect of telework on relocation is uncertain because it was calculated with proxy elasticities, as no long-term studies of that rebound effect exist.

Even if half of the energy savings from telework is lost to rebound effects, it would represent a very low cost, or negative cost, way to reduce emissions of CO_2. Telework is usually agreed upon voluntarily by the employer and employee with the understanding that they provide net benefits to both parties[26]. Thus they can be seen as having negative cost, or net benefit, to society.

26. It should be noted, however, that this does not guarantee net benefits for society. As pointed out in a US National Research Council report (NRC 1994), there are several potential negative societal impacts from increased telecommuting and "distributed work". These include the possibility of "a fragmented populace that is increasingly able to segregate itself into homogeneous strata. The ability to enjoy a distributed work style may be inequitably distributed, and the socioeconomic gap between the information 'haves' and 'have nots' may continue to widen. The off-shore relocation of some location-independent work, increased automation of jobs, and associated organizational restructuring may contribute to increased domestic unemployment" (CSTB 1994). Finally, greater flexibility for workers in choosing where to live may further exacerbate urban sprawl and result in too-rapid growth in rural areas.

An Aggressive Telework Strategy for Ireland

Ireland's recent economic boom has been driven in part by strong growth in the telecommunications and computer sectors. At the same time, the country's telecommunications infrastructure has been rapidly improving. Yet the percentage of teleworkers in Ireland, at 4.4% of the population, is below the European Union average of 6%. Since much of the growth in jobs and accompanying traffic congestion is concentrated around Dublin, with many rural parts of the country suffering from high unemployment, telework is seen as an attractive policy option in Ireland. In 1998, the government formed the National Advisory Council on Telework that produced the major report, "New Ways of Living and Working: Teleworking in Ireland" in May of 1999. (The report can be found at http://www.telework.ie/NACT.) This report contained a set of recommendations to the Irish government on policies to promote telework around the country, with some of the most aggressive measures proposed in an IEA country to date. The government appears to agree with most of the report's recommendations and has begun undertaking many of the proposed initiatives. For example, it has already ratified a new "code of practice" to govern telecommuting, is developing an education plan to promote telework and expand its use, and has submitted a plan to the Parliament that involves changing the tax code to include telework incentives. The government is also pursuing major investments in broadband communications infrastructure and pilot programs to establish telecommuting programs in different areas.

Can policy makers do more to encourage the expansion of telework beyond its currently rapid pace? Government so far has had its greatest effect on telework by assisting in the development of the telematic infrastructure. Employer and employee access to high bandwidth telecommunication lines has been the impetus for most of the growth in telework in the past ten years. Telework has grown dramatically in some countries, and is projected to continue to increase rapidly in the next several decades without any specific telework policies.

Governments, however, can encourage even faster growth in telework by providing incentives to businesses to create telework opportunities for employees, such as tax reductions to pay for equipment for home-based telecommuting, or even directly related to telecommuting, such as based on person-days of telecommuting. Since large numbers of individuals already telework in most IEA countries, care must be taken to avoid a large *free rider* problem, i.e., providing monetary benefits for telecommuting that would occur anyway.

Policy Example: Corporate Tax Incentives for Telework

This example looks at a set of national tax incentives for businesses that is able to increase the percentage of employees who telecommute. We consider an incentive large enough to raise the number of people in a country who telecommute at least two days per week over the next ten years by 5 percentage points (e.g. from 10% to 15%). Since telecommuters would be required to telecommute two days per week (and some would do so more often), new telecommuters would reduce their vehicle trips to work by an average of about 50%. A rebound effect could offset 50% of the reductions in fuel savings and CO_2 reductions. If commuting represents 25% of total travel and 80% of that is by single passenger car, then taking all these factors into account, total light-duty vehicle travel would decline by less than 1%. Factoring in a range of uncertainty, we estimate this example policy would reduce travel, fuel use, and emissions of CO_2 by zero to 1%. The impact of a telecommuting policy might decline over time, since it may accelerate the growth of telework but may not ultimately change the final level in the long term.

Combining Traffic-reduction Policies

This section considers combining a number of policies to reduce vehicle travel. Implementing a package of policies could yield greater and perhaps more cost-effective reductions in CO_2 emissions than individual policies, if they complement one another. While interactions among policies are often complex and difficult to estimate, certain types appear appropriate to combine. These include policies that discourage private vehicle travel and encourage transit and non-motorized transport, such as increases in the costs of personal vehicle travel or parking, improvements in transit service, and the promotion of non-motorized forms of transport. Measures that improve traffic flow may not fit into this set, however, since they tend to encourage greater levels of vehicle use.

Measuring the net impacts of two or more different measures is difficult, although some recent modeling efforts suggest that the synergies from policies that reinforce each other may be substantial. For example, NOVEM's modeling work for the Randstad region estimates that a package of increased parking fees, decreased parking availability, and improved public transit can nearly double the CO_2 emissions reductions compared to the sum of reductions of the three measures implemented separately. Improving transit offers more travel choices for those who face higher charges for a declining number of parking spaces. Improving transit may also increase the political and societal acceptability of parking measures.

Policy Example: Combining Traffic Reduction Policies

While estimating the effects of combined policies in any rigorous fashion is outside the scope of this book, this example policy makes the point that synergies can be derived from them. We bundle three strategies that were considered earlier in this chapter: a national tax on parking, a subsidy to reduce transit fares, and improvements in the infrastructure for non-motorized transit – a package similar to one assessed by NOVEM. Based on their analysis, we estimate that fuel use and emissions of CO_2 would fall by at least as much as the sum of reductions for the three measures (reported separately above). There could also be synergistic effect adding up to 50% more reduction when the policies are combined. Thus, fuel use and CO_2 emissions would decline by at least 4%-11% by 2010 and 5%-14% by 2020, and by as much as 16% by 2010 and 21% by 2020 (see Table 3.2). The broadness of these ranges reflects a high degree of uncertainty, in part due to the wide variety of cities and countries the measures could be applied to.

Table 3.2

Combination of Three Travel CO_2 Reduction Policies

Policy	2010 estimated CO_2 reduction	2020 estimated CO_2 reduction
Improved transit systems	0-1%	0-1%
Parking-related measures	4-7%	5-10%
Promotion of non-motorized modes	0-3%	0-3%
Combination of three policies	4-16%	5-21%

4 ALTERNATIVE FUELS

Almost 99% of today's energy supply for road transport in OECD countries derives from crude oil (69% gasoline and 30% diesel), while the most important alternative fuels, liquid petroleum gas (0.9%) and compressed natural gas (0.05%) hold minuscule shares. Thus, road traffic depends almost entirely on vehicles powered by petroleum fuels. As a result, greenhouse-gas emissions per liter of fuel consumed have not changed significantly over the past 50 years, notwithstanding numerous initiatives in different countries to promote the use of new fuels, some of which may emit fewer greenhouse gases than petroleum fuels on a *life cycle* basis.

Researchers and governments have identified a number of potential alternative fuels for vehicle transport, including[27]:

- Liquefied Petroleum Gas (LPG), usually composed mostly of propane, from refineries and natural gas associated with oil wells.
- Natural gas, compressed or liquefied (CNG and LNG).
- Methanol from natural gas or cellulosic (woody) biomass.
- Ethanol from starch-rich or sugar-rich crops, or from cellulosic biomass.
- Biodiesel, esterified oil from crops containing vegetable oil.
- Hydrogen by electrolysis of water or reforming of a variety of fuels.
- Dimethyl-ether (DME) from natural gas.
- Gasoline and diesel fuel from synthesis of simpler compounds such as natural gas (using a Fischer-Tropsch process, for example).

Some alternative fuels can be blended with conventional fuels for use in today's vehicles. The advantage of using blends compatible with current vehicles is that they do not require major investments in vehicle

27. The alternative fuels are described in more detail in the IEA publication "Automotive Fuels for the Future" (IEA, 1999).

or refueling infrastructure. Ethanol, for example, can be blended with gasoline, and biodiesel can be blended with conventional diesel fuel. But not all blends function well in a conventional vehicles. Current gasoline engines can run without problems on a gasoline-alcohol blend with as much as 15%-20% alcohol by volume. With minor modifications, gasoline engines can run on a much wider range of gasoline-alcohol fuel mixtures. These modified *fuel-flexible* vehicles are usually designed to handle a blend of up to 85% alcohol by volume. Many diesel vehicles on the market, which can operate on diesel-biodiesel mixtures without modification, are already fuel-flexible vehicles in all but name.

Alternative fuels have not penetrated most transport markets significantly in most countries due to the omnipresence of gasoline and its price advantage compared to some alternative fuels, and the wide variety of gasoline vehicles, their superior performance, and low cost.

One major obstacle to marketing alternative fuels is the absence of a refueling infrastructure. An alternative fuel needs a widespread system for public refueling so drivers can refuel when needed without searching too far. Developing such an infrastructure is expensive and difficult. Fuel providers have little incentive to create such a system if no apparent market for their fuel exists, that is, if no alternative fuel vehicles are on the road. On the other hand, vehicle manufacturers have little incentive to produce vehicles for which there is no fuel publicly available. (See the section below on market barriers for a broader discussion of this topic). Overcoming these and other market barriers requires a major policy initiative by national, and/or regional and local governments.

The development of fuel policies in general, and alternative fuel policies in particular, is driven by a number of factors – the goal of reducing emissions of CO_2 is just one of them. Air pollution abatement or oil displacement may take precedence over reduction of CO_2 emissions. Abundant gas reserves or the availability of large amounts of biomass in a given region may lead to fuel choices different from those in areas with abundant oil reserves. Support for local industry or farmers may figure into fuel policies.

French Government Incentives for Alternative Fuel Vehicles

Over the past few years, the French government has established a number of programs to promote alternative vehicles. This policy initiative aims at increasing their use in specific fleets, such as electric vehicles for corporate and some public service fleets; compressed natural gas (CNG) vehicles for heavy vehicles such as buses and garbage trucks; and, liquefied petroleum gas vehicles for professional and private users with high annual travel rates.

The French programs include regulatory and fiscal elements. Regulations include requirements that some public entities managing fleets of more than 20 vehicles must purchase "clean" (i.e. low-emitting) vehicles; these must be 20% of new vehicle purchases. Fiscal measures include financial assistance for the acquisition of electric and CNG vehicles. The Law on Air and Rational Use of Energy (Loi sur l'Air et Utilisation Rationnelle de l'Energie, 30 December 1996), provides funds for costs related to choosing, buying, and using alternative fuel vehicles:

- *Reimbursement of 50% to 70% of the cost of fleet orientation and diagnostic studies that assist in the choice of vehicle and fuel system.*
- *Funding for the acquisition of alternative fuel vehicles for use in demonstration programmes.*
- *Incentives that narrow the difference in prices between alternative and conventional fuel vehicles.*
- *Provisions for reimbursement of taxes on alternative fuels under some circumstances and other tax credits.*

Source: SERURE 2001.

The Potential for Lower CO_2 Emissions

Alternative fuels do not necessarily emit less greenhouse gases than gasoline when used to power a vehicle. Most alternative fuels do contain less carbon per unit of energy than gasoline, but do not necessarily emit less total emissions *well to wheel* – including emissions from the extraction of the alternative fuel or feedstock (if applicable), energy used in its production, distribution and storage, and its use in vehicles. Taking into account all of these emissions is called *full fuel cycle* or sometimes *life cycle* analysis.

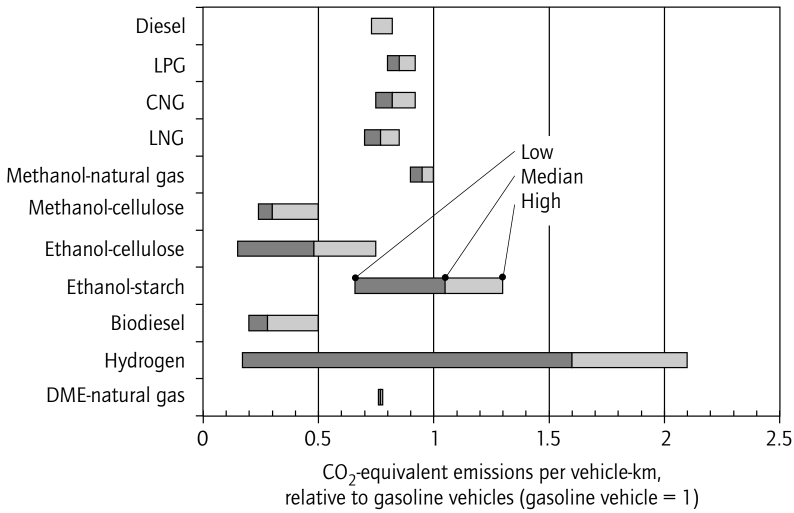
Life-cycle emissions for a fuel vary from country to country. Electric vehicles may have nearly zero total emissions when recharged with electricity generated by nuclear power or renewable sources, but may have higher total emissions than gasoline vehicles if recharged with electricity from coal plants.

Still, a few alternative fuels promise substantial reductions of greenhouse gases on a full fuel-cycle basis everywhere. These include ethanol and methanol under certain circumstances, namely when these alcohols are derived from cellulosic (woody) feedstock using advanced, low-energy production processes (current commercial alcohol production for transport in IEA countries does not use advanced processes and does not provide greenhouse gas reductions compared to gasoline). Other low greenhouse gas fuels include biodiesel and potentially hydrogen, if used in highly efficient fuel-cell vehicles and if produced from renewable or other low GHG feedstocks.

A recent report by the IEA, in co-operation with the Advanced Motor Fuels Implementing Agreement, gives estimates for full fuel cycle CO_2 emissions for gasoline and a number of alternative fuels, based partly on a survey of studies (IEA/AFIS 1999). Figure 4.1 shows these estimates for each major alternative fuel compared to gasoline (with a reference value of 1). The range of estimates for some fuels is broad, as shown by the bands around the median estimate for each fuel in the figure, reflecting differing assumptions about the characteristics of the fuel cycle (source for hydrogen, etc.). Looking at the median emissions of CO_2 for each fuel, only cellulosic alcohols (ethanol and methanol) and biodiesel promise large reductions – that is, 25% or more – compared to gasoline in the short term. The net reduction for hydrogen depends on how the hydrogen is obtained. Ethanol produced from grains using conventional harvest and distillation techniques has relatively high emissions. Electric vehicles were excluded, since their reductions are highly dependent on how the

Figure 4.1

Short-term CO_2-equivalent Well-to-wheel Emissions of LDVs on Different Fuels[28]



electricity is generated. Recent diesel vehicles, particularly those with turbo-direct injection engines, running on low-sulfur diesel fuel, have full fuel cycle CO_2 emissions that are about 25% less than those of similar conventional gasoline vehicles.

In the longer term, after 2010, life-cycle CO_2 emissions are likely to decline in any case, due to expected improvements in vehicle efficiency. For fuels that have a high share of upstream emissions, such as hydrogen and biomass-derived alcohols, improvements and changes in fuel processing may also play an important role. For most fuels, we estimate a 5%-10% efficiency increase in the production and distribution of fuels, and 50%-55% in vehicular efficiency for all fuels used in three-liter combustion engines. Under these assumptions,

28. Notes for Figures 4.1 and 4.2: Performance relative to a 1996 gasoline light-duty vehicle. The gasoline reference value is one; 0.5 marks 50% the CO_2-equivalent emissions of the reference vehicle. Ranges in data result from local variations between fuel routes and differences in technology that may occur at all stages of the well-to-wheel fuel chain.

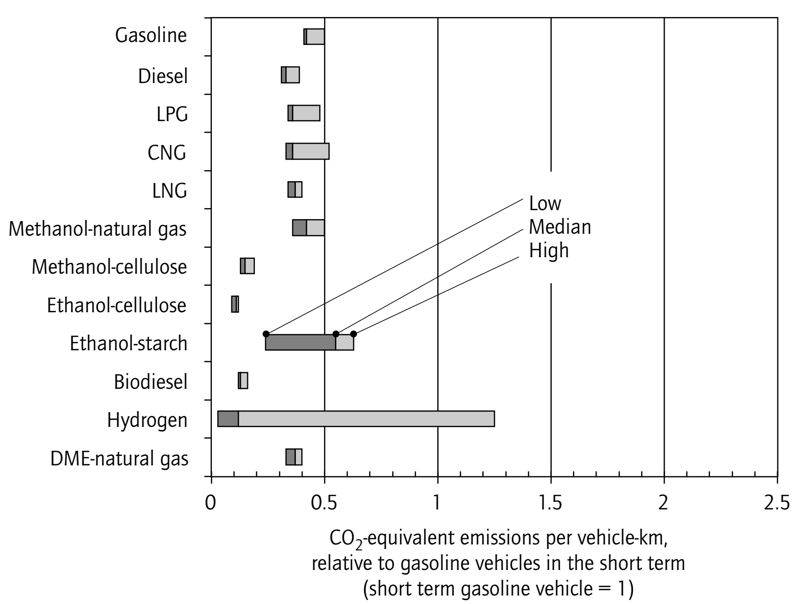
almost all fuels – including gasoline in gasoline vehicles – would emit half or even less CO_2 on a life-cycle basis than today's gasoline vehicles (Figure 4.2). The fact that most technological advances for vehicles can be applied to gasoline vehicles just as easily as alternative fuel vehicles is often overlooked. Some fuels, however, such as cellulosic ethanol, promise even greater long-run reductions relative to gasoline, due to expected advances in upstream processes.

Oil Displacement Potential

An alternative fuel can reduce oil dependence and CO_2 emissions only if it can meet a significant part of automotive fuel demand. In the near term, through 2010, this potential depends on whether an alternative

Figure 4.2

Long-term Well-to-wheel CO_2-equivalent Emissions of LDVs on Different Fuels



fuel can use the existing infrastructure or quickly develop its own for feedstock production and conversion to a finished fuel; fuel distribution and retailing, and use in available vehicles. Considering each of these areas, this section examines whether several alternative fuels – biofuels, liquid petroleum gas, natural gas, hydrogen and dimethyl ether – could substitute for 10% of automotive fuel consumption on an energy basis in the next ten years. In the near term, over at least the next five years, no fuel appears capable of displacing even 10% of oil demand in road transport in most IEA countries. Taking the longer view, however, several fuels look promising. These include liquid petroleum gas, natural gas, hydrogen and dimethyl ether. Biofuels, such as methanol or ethanol derived from cellulosic crops, could reach 10% in some regions, but doing so would require substantial changes to agricultural systems that may be unrealistic in many countries (Figures 4.3 and 4.4).

Feedstock Production and Fuel Conversion

Whether a non-oil fuel can substitute for 10% of automotive fuel consumption in the short term depends in part on whether sufficient

Figure 4.3

Meeting the Ten Percent Criterion across the Fuel Chain: Short Term

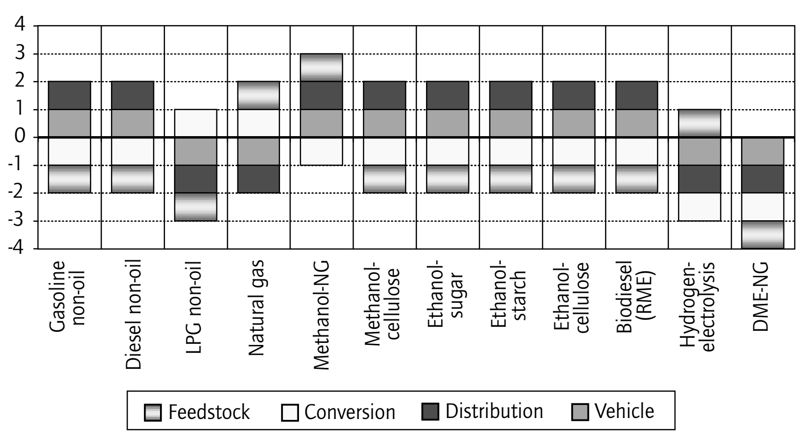
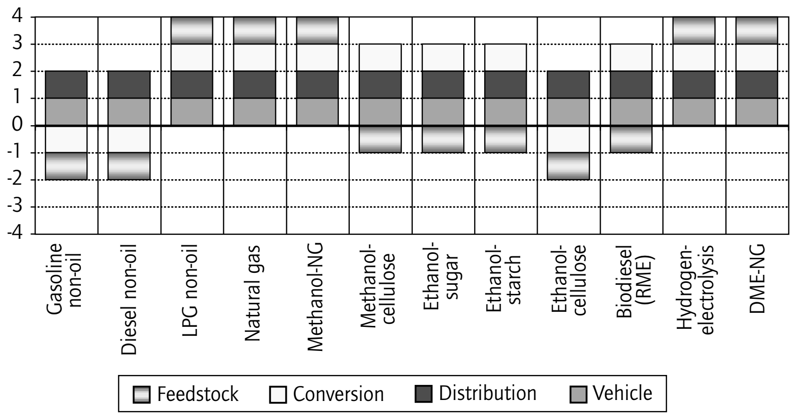


Figure 4.4

Meeting the Ten Percent Criterion across the Fuel Chain: Long Term



feedstock supply and conversion capacity already exists. Given the global abundance of natural gas, there is enough available to meet a 10% target for natural gas used directly as a motor fuel, or for production of fuels derived from gas (such as methanol from natural gas and hydrogen reformed from gas). These could meet the 10% target for feedstock supply in the short term, and in the long term so could most other fuels, except for bio-alcohols, biodiesel and synthetic gasoline and diesel fuel (i.e. from non-oil feedstock). However, conversion capacity is a different story: only natural gas as a direct fuel (requiring no conversion) and liquefied petroleum gas could meet the 10% criterion in the short term. In the long term, sufficient conversion capacity could be built for all fuels except perhaps for synthetic (non-oil) gasoline and diesel, and ethanol from cellulosic material. For these exceptions, conversion technologies remain experimental.

Issues Associated with Production and Conversion of Each Fuel

Biofuels: The production of feedstocks for biofuels resembles raising crops for food or industrial uses, except that the varieties may be different. Alcohol is currently made in most IEA countries from starchy crops such as corn, but for significant greenhouse gas reductions, cellulosic crops would be needed with new conversion processes. Cellulosic feedstocks for methanol or ethanol could be agricultural or forestry by-products, such as straw and wood waste, or woody crops like switchgrass and short-rotation coppice. Most of the feedstocks of concern here are already produced on a commercial scale. The technology for making alcohol from cellulosic biomass exists. Research is under way in IEA countries to increase the efficiency of this technology in order to increase outputs and reduce production costs.

Is enough land available to grow these crops? Table 4.1, which estimates the agricultural area needed to meet the 10% target for each biofuel, shows that in the long term only two fuels – ethanol from sugar beets (or other high-sugar feedstocks) and methanol from cellulosic materials – are considered likely to be able to displace 10% of automotive fuel demand. The other fuels require so much land that they are unlikely to meet the target, unless yields rise sharply.

Table 4.1

Land Needed to Produce Feedstocks for Biofuels under the Ten Per Cent Substitution Criterion

(Units of 10^7 ha and as percentages of total world cropland of 144×10^7 ha in 1992)

	Short term		**Long term**	
	10^7 ha	Per cent	10^7 ha	Per cent
Methanol from cellulose	5.6	4	8.4	6
Ethanol from cellulose	9.74	7	14.66	10
Ethanol from starch (wheat)	10.3	7	16	11
Ethanol from sugar beet	3.7	3	5.6	4
Biodiesel	12	8	17	12

Notes: *These are estimates derived from European data on yields per hectare, feedstocks needed for a ton of fuel and the energy content of that fuel. Production-capacity calculations assume that enough good-quality hectares exist for production of the crop or similar crops with comparable yields per hectare. The estimates of the areas required assume constant yields.*
Source: IEA/AFIS 1999.

Liquid Petroleum Gas (LPG): LPG can be derived either as a side product from natural gas wells or as a product of oil refining[29]. Its current production from gas wells could meet the short-term target as an automotive fuel, but only if it is diverted from present uses. LPG from expanded production could probably meet the 10% criterion, given some time for new investments in facilities, as production of LPG is a proven technology, is easily expandable, and likely to increase as a by-product of increased natural gas production and decreased flaring. LPG can also be made with synthesis gas from coal, natural gas or biomass.

Natural Gas (and liquids from gas): Enough natural gas is available worldwide to meet short-term and long-term targets for feedstock supply. Most production sites presently operate at maximum capacity for only part of the year. World supplies exceed proven oil reserves by more than 20%. But distribution of natural gas outside existing pipeline systems is expensive and limited in capacity (due to limited numbers of liquefied natural gas terminals and ocean tankers). In the long term, converting natural gas to a transportable liquid such as methanol or dimethyl-ether (DME), which also is a viable fuel for vehicles, may be more practical. Gas capacity reserves are sufficient to meet the 10% target for liquid fuels such as methanol or DME as well as for gas itself. However, much more gas is needed to produce an equivalent amount of methanol or other liquid fuel than if it is used directly as a motor fuel, due to conversion losses. Whether enough conversion capacity to produce liquid fuels from CNG exists to meet the 10% target within five years is more difficult to assess. There is considerable methanol capacity; using the excess may enable a quick increase in production, but more capacity is probably needed to reach the 10% target. Like methanol, DME can be produced from any hydrocarbon-containing feedstock. Almost no DME capacity yet exists, but some methanol plants with excess capacity could be retrofitted to DME production for the medium term. Following the invention by Haldor Topsøe of a more efficient production process, DME will

29. LPG production in refineries stems from crude oil and is therefore oil-based. It is not included in this analysis.

probably be produced from natural gas in the future. DME production from biomass is also possible, but no tests have yet demonstrated its practicality or cost.

Hydrogen: Hydrogen has good prospects for the long term but not for the short term. It is produced on a large scale for the chemical industry and can be made from many feedstocks. Today's output equals 7% of the energy consumed by road vehicles. Although production probably cannot be diverted or expanded sufficiently in the short term to meet the 10% target, it could, without any apparent technical difficulties, for the long term.

Support for Biofuels in the European Union

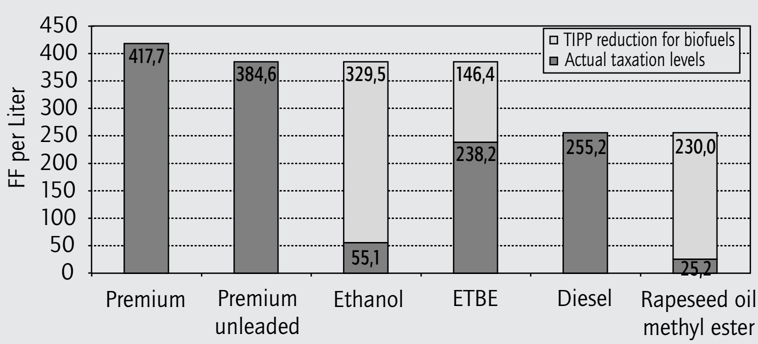
European Union production of biofuels, which includes ethanol produced from fermentation of beets, corn, barley and wheat, and biodiesel (methyl ester) obtained from sunflower and rapeseed oil, has been increasing strongly in the past decade. Production of biodiesel rose from 55 000 tons in 1992 to 470 000 tons in 1999, with more than 50% produced in France. Total EU production of biofuels, however, is less than 1 million tons, i.e., around 5.9% of world production estimated at 17 millions tons. This amount represents less than 1% of total fuel in the European road sector, a market share that is well below that of Brazil and the United States.

Increased use of biofuels in transport is part of the European Union's strategy for developing renewable energy, as mentioned in its Green Paper for a Community Strategy "Energy for the Future: renewables sources of Energy" (1997) and in its Strategy Communication "Campaign for Take-Off Awards: Renewables Energy for Europe" (1999-2000). The European Commission estimates that Member countries could produce 5 million tons of liquid biofuels by 2003 (which is about 2% of current fuel consumption), and 18 million tons by 2010. However, unless steps are taken to move toward low-greenhouse gas fuels such as cellulosic ethanol, this program may have little impact on reducing greenhouse emissions, even if it displaces significant oil.

In Europe, as in other regions, the cost of producing biofuels is two to four times higher than for gasoline or diesel. For biofuels to be competitive, they must be supported by subsidies or other advantageous fiscal measures that lower their price relative to conventional fuels. The EU offers no such incentives, but is supporting and promoting research, demonstration and pilot projects for biofuels, particularly through ALTENER, the European Program to Promote the Use of Renewable Energy Sources. However, four member states of the EU (France, Spain, the Netherlands, and Sweden) do have fiscal programs for increasing production of ethanol. France has encouraged biofuels with a partial exemption of the TIPP (Taxe Intérieure de Consommation sur les Produits Pétroliers or the Domestic Tax on Consumption of Petroleum Products) since 1992. This exemption is FRF 2.30/euros 0.35 per liter for rapeseed oil and methyl ester, and FRF 3.29/euros 0.50 per liter for ethanol. The following chart, which compares the taxes of different fuels in France, shows that the price incentives for biofuels are strong.

Source: ADEME, personal communication.

Comparison of Taxation of Different Fuels in France (January 2000)



Distribution and Retailing Infrastructure

A distribution and retailing infrastructure large enough to supply a 10% share of an alternative fuel could be ready in the short term for most fuels that are compatible with today's vehicles, but not for non-compatible fuels such as liquid petroleum gas, natural gas, hydrogen, and dimethyl-ether. Meeting the long-term target presents no technical difficulties for any fuel, if the commitment to build compatible vehicles is made.

LPG requires special distribution facilities, but countries like the Netherlands and Italy already use that technology on a large scale; other countries would need time to replicate it. Natural gas can move through gas grids, if available, in which case only the refueling appliances need to be installed and connected to the grids. Otherwise, natural gas can move in road tankers and be stored at refueling stations (both storage tanks and refueling appliances would need to be installed at stations). Hydrogen-distribution technology is proven but not yet tested on a large scale. DME can be distributed by truck, as it is currently for non-transport applications. Vehicle refueling with DME is unproven, but because it resembles LPG, refueling should not pose a problem for the long term. Getting alcohols, or alcohol-gasoline blends to market, closely resembles the process for gasoline. The most important change involves ensuring that the entire fuel-handling system (and vehicles running on alcohol) are equipped with alcohol-resistant materials. Newer refueling stations have already been modified. The distribution and refueling of biodiesel are the same as for diesel.

Existing Vehicle Use of Fuels

If an alternative fuel is to replace 10% of current fuel in the short term, existing gasoline and diesel vehicles must be able to use it. Several fuels cannot meet that requirement.

Running conventional vehicles on liquid petroleum gas or natural gas requires expensive retrofitting. Liquid petroleum gas and natural gas vehicles are already produced and used in large numbers in some countries, but they do not dominate vehicle markets at this time in any country. Most LPG and CNG vehicles are aftermarket conversions, not produced directly by original equipment manufacturers.

Alcohols can be blended with gasoline for use in conventional gasoline vehicles, but can barely meet the 10% target this way. On an energy basis the target would require about a 15% blend of ethanol on a volume basis, and nearly 20% for methanol, which is near the limit of what current engines will tolerate. Conventional engines begin to experience problems, such as cold starting, when alcohol volumes in gasoline approach 20%. Methanol also requires increased use of stainless steel for fuel-system components to avoid corrosion. Both fuels can be used as blends in fuel-flexible vehicles, up to volumes of 85%. Fuel-flexible vehicles are essentially conventional vehicles with slightly modified engines and fuel systems that increase the tolerance for alcohol use. These engines usually cost USD 100-USD 200 more than conventional engines. In the United States, more than 100 000 fuel-flexible vehicles are being manufactured each year, although few currently run on anything other than conventional gasoline or blends up to 10% ethanol.

Hydrogen is undergoing field testing in modified internal combustion engines and in fuel cells, a radically different propulsion technology (see discussion of fuel cells in Chapter 1). The use of dimethyl-ether has been demonstrated, but not without problems with lubrication and fuel pumps that wear too quickly. Biodiesel and oil-derived diesel have few chemical differences, so conventional diesel vehicles need few modifications to use them. Recommended modifications, like biodiesel-resistant synthetic parts, are already appearing on many new diesel vehicles.

In the long term, there are no fundamental technical barriers likely to prevent cars from being built to accept any of these alternative fuels.

The Complete Fuel Chain

Looking at the whole picture, taking into account feedstock production, conversion to finished fuel, fuel distribution and vehicle compatibility, no fuel could meet all four targets and displace even 10% of oil use in road transport in the next five years. But in the longer term, several fuels look promising: liquid petroleum gas, natural gas, hydrogen and dimethyl-ether. Biofuels, such as ethanol from sugar-rich crops and methanol or ethanol from cellulose, could technically meet a share of 10%, but require changes to agricultural systems that may be unrealistic.

Overcoming Market Barriers

While several alternative fuels could eventually displace 10% of oil use in vehicles, whether they *will* do so is a different matter. Market barriers currently prevent most fuels from even starting to enter the market in most countries, and may continue to do so for a long time. A recent report by the IEA and IEA's Implementing Agreement on Advanced Motor Fuels (1998) lists 60 potential and known barriers grouped into the following eight categories:

- Technical problems (in fuel production, fuel distribution and vehicle use – including those mentioned in the previous section).
- Public acceptance.
- Costs.
- Geographical constraints (such as the high cost of delivering natural gas to some locations).
- Legislation and institutional barriers.
- Safety and environmental barriers.
- *Chicken or egg* barriers.
- Non-recognition of advantages (such as general unawareness of the environmental benefits from some fuels).

The report identifies 21 technical problems alone. These include issues such as slow refueling and limited vehicle range per refueling. Such deficiencies are likely to discourage consumers from purchasing certain vehicles. But even if all the technical deficiencies could be overcome, other serious issues such as safety and high cost would have to be addressed for many fuels and fuel/vehicle combinations. Perhaps one of the toughest problems is the *chicken or egg* dilemma: encouraging consumers to purchase alternative fuel vehicles of limited choice and fuel infrastructure, while encouraging auto companies to invest in manufacturing vehicles and fuel companies to provide fuel for a nascent market. Not all barriers apply to all alternative fuels and vehicles, and some face relatively few barriers (such as fuel blends that can be used in existing vehicles). Barriers other than cost for certain fuels and vehicles are outlined here; cost is addressed in the following section.

Fuel blends that are compatible with existing gasoline vehicles have few barriers except those specific to certain fuels, such as fuel handling for methanol.

Alternative fuel vehicles using gaseous fuels such as compressed natural gas and liquid petroleum gas are expensive, have limited range, and long refueling times. They may pose some safety concerns, and present potentially large supply-demand dilemmas. The latter is especially true for compressed natural gas, since most countries have little or no gaseous refueling capacity for vehicles, and many lack gas pipeline distribution networks or domestically available gas.

Fuel-flexible vehicles (FFVs) and dedicated alcohol vehicles which allow proportions of alcohol in an alcohol-gasoline blend exceeding 15%-20% are, except for a few engine and fuel line modifications, similar to existing gasoline vehicles. The incremental cost of mass producing FFVs is low and not an important barrier. The major obstacle is the supply-demand dilemma of manufacturers making the commitment to produce them. Auto manufacturers in the United States, however, have begun to build large numbers of FFVs in the past few years; production is expected to approach 1 million per year in the 2001 model year (Bechtold 2000). Such high levels of FFV production in the United States, despite the unavailability of much alcohol fuel, may be motivated by a desire by manufacturers to produce what are perceived to be *green* vehicles, gain fuel economy credits under national fuel economy regulations, or take relatively inexpensive steps to promote alternative fuels.

Electric vehicles that are being developed and marketed are expensive and perform relatively poorly due to their low range and long refueling times. It is unclear whether their cost will decline and performance will improve greatly in the near term. They have, however, become an important niche market vehicle. Sales in certain vehicle classes, such as small delivery vans, have been sizeable in some countries. They benefit from government incentives in areas, such as Southern California, where zero local emissions are important. The future of electric vehicles for the mass market depends on whether a new generation of batteries with higher power density and lower cost can be developed.

"Next generation" vehicle technologies and fuels, such as fuel-cell vehicles running on hydrogen, are currently be developed and tested, and are expected to be expensive at least through 2010. In contrast, gasoline/electric hybrids have developed quickly in recent years. Light-duty hybrids are being commercially marketed by a number of companies. However, these are all gasoline models, that is, none are equipped to be externally *plugged* and charged with electricity. Thus, they are essentially high-efficiency, low fuel-consumption gasoline vehicles rather than alternative fuel vehicles. (See Chapter 2 for a more detailed discussion about fuel cells and hybrids).

Vehicle and Fuel Cost

Probably the most critical barrier that vehicles and fuels must overcome is cost. It is difficult to estimate the real incremental cost for most alternative fuel vehicles, as few models are in production, and of those, production runs are small and incremental costs are therefore quite high. Some companies appear to be subsidizing low-production runs of alternative fuel vehicles in order to sell them, and writing off the losses

Table 4.2

Alternative Fuel Vehicles for Sale in North America in 1999

Fuel type	Vehicle class	Estimated premium (US dollars)
CNG	Full size sedan	5 000
CNG	3/4 ton pickup 4×2 – regular cab	3 800
CNG	3/4 ton cargo van	5 500
Bi-fuel CNG	Compact sedan	5 000
Bi-fuel CNG	1/2 ton pickup 4×2	5 400
Bi-fuel CNG	3/4 ton pickup 4×2 – regular cab	5 000
Bi-fuel CNG	3/4 ton cargo van	5 700
Bi-fuel propane	1/2 ton pickup 4×2	5 000
Bi-fuel propane	3/4 ton pickup 4×2 – regular cab	4 500
Bi-fuel propane	3/4 ton cargo van	4 300
E85	Intermediate sedan	700
Electric	Compact pickup	21 400

Source: Levelton 1999. CNG = compressed natural gas; E85 = vehicle requiring ethanol 85% by volume (maximum 15% gasoline).

as part of their research and development costs. Table 4.2 shows recent data on list prices of alternative fuel vehicles for sale in North America and their price premia compared to gasoline versions of the same model. The list excludes fuel-flexible gasoline/alcohol vehicles, of which a number of models are available at no price premium.

In general, the incremental cost of alcohol vehicles (optimized to run on 85% ethanol, rather than configured to be fuel-flexible) appears to be less than USD 1 000, while the incremental cost for compressed natural gas, liquefied petroleum gas vehicles, and gasoline/gaseous bi-fuel vehicles, is USD 3 000 to USD 6 000. At USD 20 000, electric vehicle price increments are high but this may reflect current low production levels of under 10 000 vehicles per year.

The IEA/AFIS (IEA/AFIS 1999) study estimates a global average for the effective driving costs of alternative fuels in the near and long term, based on the price of energy per unit of the fuel and estimated vehicle efficiency per unit, which is essentially distance (Table 4.3)[30]. This table suggests that few fuels are likely to be cheaper than current fossil fuels, especially diesel, after factoring in both the full set of costs of

Table 4.3

Estimated Well-to-wheel Fuel Costs

	Total well-to-service-station costs[1] (USD/GJ fuel)		Vehicle efficiency (%)	Effective driving costs (USD/GJ vehicle performance)[2]	
	Short term	Long term		Short term	Long term
Gasoline	9.75	17.95	25[3]	39	72
Diesel	8.90	16.30	28	32	58
LPG					
Field	ND	ND	20[4]	ND	ND
Refinery	9.90	16.20	20[4]	50	81
CNG	4.30	14.20	20[4,5]	22	71
Methanol					
Natural gas	11.40	18.20	20	57	91
Cellulose	24.30	16.80	20	122	84
Ethanol					
Cellulose	41.10	25.20	20	206	125
Starch	26.60	37.50	20	133	188
Biodiesel (RME)	18.90	29.50	28	68	105
Hydrogen[6]	ND	ND	25	ND	ND
DME	13.20	20.00	28	47	71

Source: IEA/AFIS, 1999.

Notes: 1. Cost per unit of energy of the fuel available at the filling station. 2. Cost on the basis of mechanical energy performed by the vehicle, which has a direct relation to the driving distance. The transportation performance is the ultimate basis for comparison, since this is why the vehicle is used. 3. Direct injection. 4. Using a stoichiometric air/fuel mixture in a combustion engine. 5. Estimated. 6. Internal combustion engine. ND = No data.

30. It should be noted that: fuel prices in any particular region, particularly for non-global commodities such as natural gas, may vary significantly from the global average; that prices for fuels that are also chemicals, such as methanol, are often volatile; and that fuel taxes vary substantially by country and are often the main determinant of relative retail prices.

delivering fuel to the vehicle and vehicle efficiency. Note that these estimates do not include various existing taxes and subsidies that may significantly change the economics of some fuels in different countries.

Fuel prices may be especially important in determining demand for different fuels under certain conditions, when consumers are relatively indifferent about choices between vehicles of different fuel types, or if two fuels can be used in the same vehicle (such as gasoline and alcohol in FFVs) and both are available through a good retailing infrastructure. Conversely, fuel prices may not be especially important in determining a consumer's choice between different vehicle types, such as gasoline and electric, especially if the alternative fuel vehicle is much more expensive. Fuel price also is not likely to matter much for fuels that are not widely available. Finally, fluctuating prices for an alternative fuel could reduce consumer interest in choosing vehicles that use it. Multi-fuel vehicles, especially alcohol/gasoline fuel-flexible vehicles, offer consumers the possibility of purchasing the fuel with the lower price, if both are widely available.

Policy Example: Development of Cellulosic Ethanol Production

Ethanol, one alternative fuel that is compatible with the existing infrastructure for gasoline vehicles and fuel, could result in significant oil savings and reductions of CO_2 emissions by 2010. Since small quantities of ethanol (up to 15%-20% by volume) can be blended with gasoline and used with no problems in conventional vehicles, a substantial amount of gasoline could be displaced by ethanol in most countries without any major change to the vehicle and refueling infrastructure. The main constraints to such a program are the availability and cost of ethanol, particularly cellulosic ethanol (necessary if substantial reductions in greenhouse gas emissions are sought). Major costs of a blending program include the construction of ethanol production plants and the establishment of ethanol crop plantations.

This policy example involves a government-supported price incentive to refiners for blending ethanol in gasoline up to 10% by volume. Ethanol subsidies already in place in the United States and Canada are largely responsible for the growth in production of ethanol motor fuel in those countries. Ethanol accounts for nearly 3% of light-duty vehicle fuel consumption in the United States. These programs, however, do not make a distinction between grain ethanol and cellulosic ethanol, or other approaches that reduce fuel-cycle greenhouse-gas emissions relative to gasoline. The subsidy in this example would be restricted to ethanol with full fuel-cycle GHG emissions no more than 33% that of gasoline. Table 4.3, and recent studies for the United States and Canada (e.g. EEA 1999), indicate that an ethanol price subsidy for refiners of around USD 0.30-0.40 per liter relative to gasoline should be sufficient to make commercial production of cellulosic ethanol viable within a few years[31]. Government outlays may actually be reduced in countries that currently subsidize all ethanol production, if they restrict the subsidy to low GHG cellulosic ethanol.

If refiners are guaranteed such a price subsidy for at least 10 years and if funding is offered for several demonstration plants from 2002 to 2004, there could be enough refinery demand for low GHG alcohol blends and enough investment in production facilities to displace 1%-2% of gasoline demand by 2010. Additional incentives to potential producers of ethanol, such as low-rate loans, might speed the rate of plant construction and displace an even greater percentage. The actual effects of incentives on the infrastructure and demand for ethanol would certainly deserve a detailed analysis for any country considering such a plan. Each percentage point of oil displaced can require a sizeable number of full-size ethanol plants. In the United States, for example, if each ethanol plant produces 250 million liters per year (about 150 million liters of gasoline-equivalent), 35 plants would be needed to satisfy each additional 1% displacement in gasoline. The

31. This estimate is based on on-going research on cellulosic ethanol production processes, that estimates that the cost of producing ethanol can be reduced to a price differential of about USD 0.30 cents per liter with gasoline by 2005. The required level of subsidy may vary in other countries, depending on the cost of crop production, the (pretax) price of gasoline, etc.

size of the effort and the amount capital investment required would be enormous.

If the subsidy could replace 1%-2% of gasoline demand by 2010, CO_2 emissions would decline 0.67%-1.33%, given a 66% reduction in CO_2 emissions per liter displaced. If the program continues for another ten years, capacity and gasoline displacement might triple by 2020. However, as ethanol production increases, land may become a significant constraint. In Europe, this might occur before 10% of gasoline can be displaced. In the United States, Canada and Australia, this constraint may be weaker. In any case, if 5%-7.5% of gasoline demand is displaced by ethanol by 2020, annual vehicle emissions of greenhouse gases (on a life cycle basis) would decline by 3.3%-5%.

Policy Example: Concentrated Fuel Infrastructure Development

Since the *chicken or egg* problem is considered a major obstacle to the success of most types of alternative fuel vehicles, this policy attempts to boost investment in alternative fuel vehicle production and refueling infrastructure to stimulate a larger consumer market.

For such a program, the national government, perhaps in co-operation with regional or local governments, would offer incentives for metropolitan areas to foster development of an alternative fuel infrastructure. Alternative fuel development zones could be created, much like the zones in the Clean Cities program in the United States, although probably with greater levels of investment into fewer areas. Each zone would choose to focus on certain types of alternative fuels and vehicles, separately or in cooperation with other zones. It would co-ordinate the development of a sufficient refueling network and encourage purchases, perhaps by local business fleets, of vehicles that match the refueling infrastructure being developed.

National governments could assist by developing guidelines for participating area programs and activities, funding and financing investments in refueling infrastructure, and, covering some costs of vehicle purchases, such as any incremental costs over conventional gasoline vehicles. Participating areas would earn a special designation (such as a *clean city*) and merit special attention. Funding should be guaranteed for five to ten years to reduce the risk of a loss of national support that might figure into investments made by individuals and companies. Program targets could be set for number or percent of refueling stations that carry specific alternative fuel or fuels.

The most obvious fuels to consider in such a program are compressed natural gas, liquefied petroleum gas, and electricity, since these fuels are the most affected by the *chicken or egg* problem. The choice should take into account local factors such as the existence of a natural gas distribution network, availability of liquefied petroleum gas, and specific air pollution problems.

For this policy example, we hypothesize that the largest metropolitan areas within a country, representing one-third of the country's population, participate in the program. These areas would develop incentives or requirements for the purchase of alternative fuel vehicles for fleets. They would require the establishment of refueling facilities for these vehicles, which must be available as retail stations to the general public. An annual sales target of 5 000 alternative fuel vehicles (mostly to fleets) would be set in each area, to be achieved by 2005, and increasing to 10 000 per year by 2010. Incentives or direct government investment in refueling infrastructure would aim to provide retail availability of the fuels at 10% of all area refueling stations by 2005, and 25% by 2010.

If those targets are met, 50 000 fleet alternative fuel vehicles and an equal number of non-fleet vehicles could be sold in the target cities by 2010. Depending on the country, this number of vehicles represents a different percentage of light-duty vehicles on the road. For France, with 25 million automobiles, 100 000 vehicles represent only 0.4% of all light-duty vehicles, but in Portugal, with about 3 million, that number is over 3%. It is assumed that some of these alternative fuel vehicles are duel fuel. If they run two-thirds of the time on their alternative fuels, gasoline use would decline up to 2%. Compressed natural gas and liquefied petroleum gas emit about 25% less CO_2 per kilometer driven relative to gasoline. If either or both of these vehicles are selected for the program, CO_2 emissions would decline around 0.5% for a country like Portugal, but only 0.1% for a country like France. Electric vehicles could result in bigger CO_2 reductions than LPG or CNG in some countries like France, but much less in others like the United States, where electricity is mostly fossil-fired.

Overall, we estimate that the program would reduce fuel consumption zero to 2% by 2010 and up to 4% by 2020 if it continues to grow and/or if a large increase in "spillover" sales to the general public of alternative vehicles occurs after 2010. Emissions of CO_2 associated with the oil savings, and fuel switching to CNG or LPG, would decline by zero to 0.5% by 2010, and up to 1% by 2020.

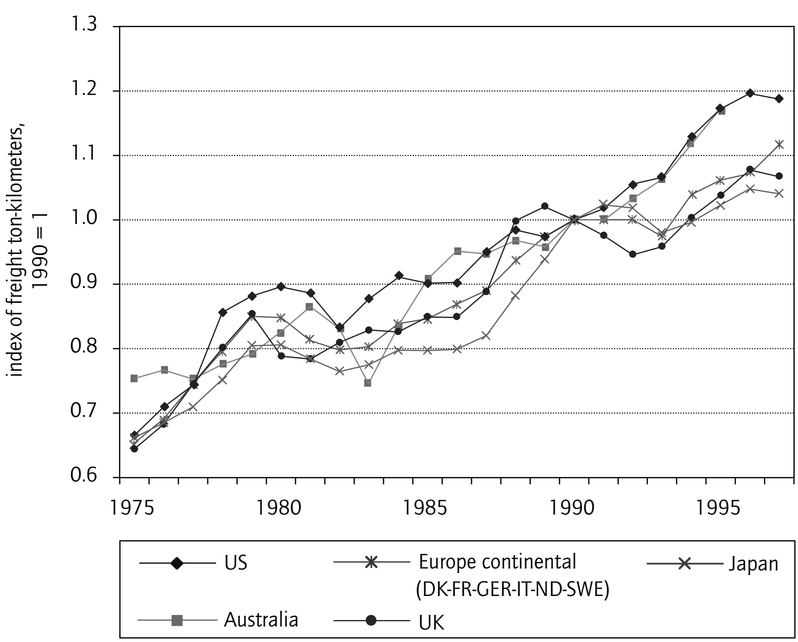
5 HIGHWAY AND SURFACE FREIGHT MOVEMENT

Growth in freight travel, measured in ton-kilometers of freight movement, has been strong in virtually all IEA countries over the past 25 years. Since 1990, freight travel has been increasing more rapidly in the United States and Australia, and less rapidly in European countries and Japan (Figure 5.1). The growth rate for the United States slowed from 1996 to 1998, however.

As shown in Figure 3 of the Introduction, freight energy use in IEA countries represents a remarkably consistent share of total transport energy use, about 30%-40%. Trucking, compared to rail and water-borne transport, accounts for the vast majority of freight energy use in all

Figure 5.1

Freight Ton-mile Travel Growth in IEA Countries



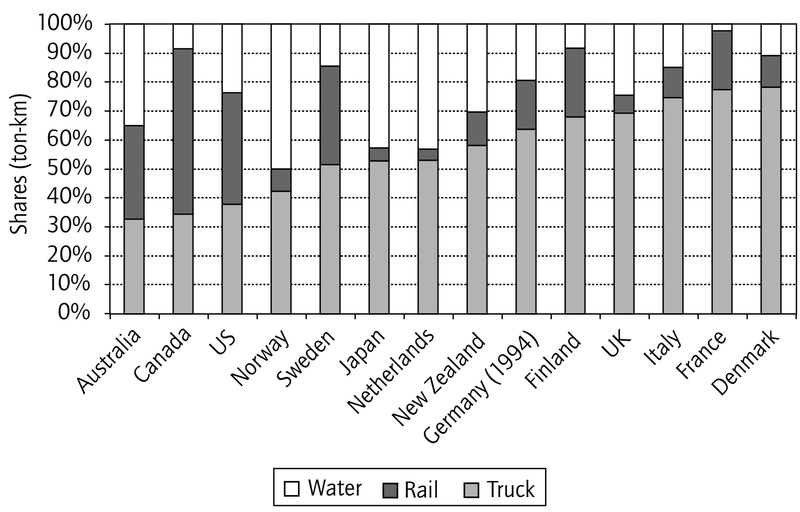
countries. This is partly because trucking moves more freight, with a share ranging from 30% to as high as 75% of total freight movement (Figure 5.2). More importantly, trucking uses much more energy per ton-kilometer of freight moved – in some countries over ten times more than other freight modes – although the range is quite broad and varies greatly by country (Figure 5.3). This chapter discusses ways to reduce freight energy use by increasing the fuel economy of heavy-duty trucks themselves, their on-road efficiency, and the efficiency of the overall freight system.

Truck Efficiency and Alternative Fuels

Fuel costs usually represent a higher percentage of operating costs for heavy-duty vehicles than for light-duty vehicles. Heavy-duty vehicles are used in commercial applications that aim to minimize costs, so heavy-

Figure 5.2

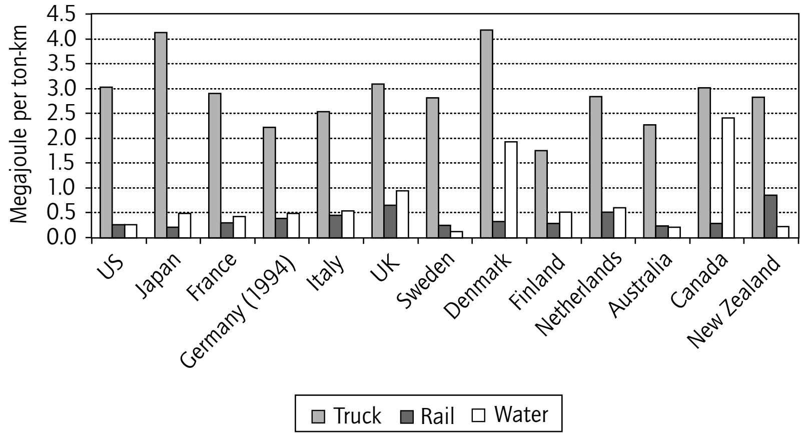
Freight Mode Shares in Selected IEA countries, 1995



Note: Data are for 1995 except Germany, which are 1994. Air freight not included.

Figure 5.3

Comparison of Modal Energy Intensities in IEA Countries, 1995



duty truck owners usually make greater efforts to achieve maximum efficiency than owners of light-duty vehicles. Heavy-duty trucks are designed to meet basic trucking company requirements for engine power, cargo capacity, and towing ability at minimum cost. Therefore, the opportunities for improving the efficiency of heavy-duty vehicles are more limited than for light-duty vehicles.

Some studies, however, indicate that opportunities exist. They show that fuel economy varies widely for trucks of the same weight class. Road tests on 11 models of 38-ton trucks conducted by *United Kingdom Motor Transport Magazine* in 1993 found that their fuel efficiency varied by 22%. More recent studies indicate a 15%-30% improvement potential for fuel efficiency for heavy trucks in the next 10-20 years. Areas for improvement include engines, the cab and trailer, unloaded and loaded vehicle weight, and rolling resistance.

Engine Improvements

Sierra Research (Sierra 1999) identifies three types of measures to improve the efficiency of standard heavy-duty diesel engines, namely reducing engine friction and parasitic losses (i.e., energy used by accessories such as air conditioning), reducing heat loss to the coolant, and recapturing and using exhaust heat energy. The first is less important for heavy-duty diesels than for light-duty diesels and gasoline vehicles, because average engine load factors are much higher for heavy-duty vehicles. In all three areas, Sierra points out that big improvements have been made since 1990, and estimates that additional improvements of only about 5% are possible by 2020. These include exhaust heat capture and reduction of coolant losses, mainly through turbocharging and advanced heat-recovery techniques that are not yet cost-effective for most trucks.

Greater efficiency gains may be possible with advanced diesel engine designs. Argonne National Laboratory (ANL 1999) projects that fuel consumption per kilometer for heavy-duty trucks could fall by as much as 18% if advanced engine technology is combined with other engine and drive train-related improvements. This estimate was made in the context of a United States Department of Energy research program on advanced heavy-duty diesels that targets an engine thermal efficiency improvement of 48%-55% from the current best practice levels, which would account for much of the fuel consumption reduction.

Advanced *next generation* technologies, such as hybrid-electric drives and fuel-cell drives for trucks, are still in the testing stage, but promise substantial additional efficiency improvements and reductions in CO_2 emissions. The California Air Resource Board recently tested a hybrid natural gas/electric heavy-duty truck, which uses a relatively small natural gas-powered engine to recharge the batteries that run the vehicle. The prototypes also included a number of other advanced technologies, such as auxiliary power systems that allow the driver to avoid idling the engine. The initial testing showed that the truck performed comparably to a diesel-powered Class 8 truck, but with up to double the fuel economy (i.e. 50% lower fuel use per kilometer) and a 90%-95% reduction in harmful exhaust emissions (California Air Resource Board 1999). A diesel-powered hybrid truck should have similar fuel economy and, with advanced emissions controls, similar pollutant emissions.

Improvements in Weight, Aerodynamics and Tires

Three recent North American studies have found great potential for improvements in heavy-duty truck fuel economy over the next ten years through improved aerodynamics, and reductions in unloaded truck weight and tire rolling resistance (Table 5.1). Using fairly conservative assumptions, Sierra estimates improvements of about 3% by 2010, but about 7% by 2020. Argonne National Laboratory makes broader assumptions about how much can done in the areas of aerodynamics,

Table 5.1

Comparison of Recent Estimates of Heavy Truck Efficiency Measures

	Tires	Aerodynamics	Weight	Total savings per vehicle
Sierra 1999	10% reduction in rolling resistance possible through 2020 yielding 2% reduction in average fuel use per km	10% improve-ment to 2/3 of new HDVs yielding a 3% reduction in average fuel use per km	600 kg of weight reduction to new HDVs yielding 0.5% reduction in fuel use	3% reduction in fuel use per km by 2010; 7% by 2020
ANL 1999	10%-20% reduction in rolling resistance possible; impact on fuel use not indicated	20% improvement in aerodynamics "may" be realistic	1 200-2 300 kg of weight reduction making extensive use of aluminum and magnesium	15% reduction (no time frame specified)
Taylor 1999	2%-3% potential fuel use reduction per vehicle	Not considered	1-3% reduction in fuel consumption per 1 000 kg reduction in weight; assumes 1 000 kg of reduction possible for HDVs	Yields 3.5% to 5.5% reduction across all new trucks by 2010

weight, and tires, for an improvement in fuel economy of 15%. Estimates by Taylor (Taylor 1999) for 2010 are more optimistic than Sierra regarding tires and weight reduction, but do not include aerodynamics. The studies do not address costs, how industry can achieve these improvements, or whether policy intervention would be needed. It is unclear whether these findings are applicable to trucks in Europe and Asia.

Increasing Maximum Allowable Truck Loaded Weights

One potentially cost-effective option for reducing the fuel consumption of heavy-duty vehicles per ton-kilometer of travel would be to increase the size of vehicles and their average loads. Size and load capacity, however, are restricted in various ways by most countries. For example, in the United States and United Kingdom, maximum loaded truck weight as of 1999 is 40 tons, while in Japan it is 28 tons. While most trucks usually operate below the weight limit, many trips are at limit. The United Kingdom Institution of Highways and Transportation has estimated that raising the weight limit to 44 tons would cut total vehicle kilometers and reduce fuel use per ton-kilometer by 4% (House of Lords 1994).

The average ton per loading of freight trucks (the ratio of ton-kilometers to vehicle-kilometers traveled) has risen sharply in recent years. In the United Kingdom, for example, vehicle-kilometers increased by 22% and ton-kilometers increased by 39% between 1986 and 1996 (DETR 1997). A similar trend was observed in Germany. These trends could reflect the use of larger trucks.

Loadings have risen despite the rapid increase in just-in-time delivery, which could be expected to result in the opposite because of the potential need for more deliveries and thus smaller loads. Firms using just-in-time delivery, however, were found to take other measures to mitigate the pressure on load factors (McKinnon 1999). These included, most importantly, the increasing use of delivery *consolidators* that co-ordinate the delivery of a variety of products, suppliers, and receivers.

McKinnon (McKinnon 1998) found that loadings can be further increased by better use of truck capacity. Looking at data on use of truck weight, cubic capacity, and available vertical space, he found that on average less than half of the available height of a truck is used. Potential approaches to improve load factors include adding more compartments to better use the upper area of the trailer, and converting single-deck trailers into double-deckers. A survey of firms operating double-deck trailers found that their use reduced vehicle-kilometers by an average 24%.

Allowing additional trailers to be attached to a truck (*long trucks*) is another approach to increasing truck haulage capacity. Taylor (Taylor 1999) estimates that switching from standard length single-trailer long-haul trucks to double or even triple-trailer configurations can reduce fuel consumption by several percent per kilometer.

However, any steps that increase the capacity and effectively lower the cost of trucking may encourage shifts in freight movement from competing modes such as rail, and would raise concerns about safety and increased roadway wear and tear. Legislation to permit multi-trailer trucks is often opposed due to safety concerns. It is argued that the longer trucks become, the worse their rate of acceleration, the more difficult they become to pass, and the more likely they are to swerve out of their lane or out of control. Many countries, however, permit multi-trailer trucks on divided highways and/or in some rural areas. In places where safety problems can be minimized, allowing increased use of long trucks may be a promising option for reducing CO_2 emissions.

Overall Potential for Efficiency Improvement

In total, these studies indicate that through improvements to engines and other systems could raise overall fuel economy for heavy-duty trucks by 15%-30% in the next 10-20 years. A 10%-15% gain would result from improvements to engines and drive trains, and a 5%-15% gain from improvements to the rest of the truck. It is unclear how much of this technology, however, would actually be deployed autonomously by industry to save fuel without policy intervention. Most *reference case* projections show truck fuel efficiency rising less than 10% through 2020 (e.g. IEA 2000 and EIA 2000).

Policy Options

There are a number of alternatives to increases in fuel prices or total fuel costs that can encourage improving the fuel economy of heavy-duty trucks. One alternative approach could directly target truck purchases. Fees and rebates based on fuel consumption (as discussed in Chapter 1 for light-duty vehicles), could reduce the effective price of the most efficient truck models. A feebate system could take into account weight class and/or purpose of the truck to encourage truck purchasers to buy the most efficient vehicles within their desired market segment. Choosing the models and identifying categories equitably would be difficult and would require careful research.

Efficiency standards for trucks, similar to the CAFE standards for light-duty vehicles in the United States, are also an option, but developing a workable system of truck classes and standards would be difficult. Developing minimum standards (i.e. maximum levels of fuel consumption) aimed at improving the worst performers in each category might be politically acceptable and offer a way to begin setting standards, but may save little fuel.

Another approach is to set fuel-efficiency targets. The Japanese "top runner" approach for light-duty vehicles identifies the most fuel-efficient models in each vehicle class and requires future models to meet a level of fuel consumption close to the current (or expected future) best. Top runner improves average fuel efficiency both by encouraging improvements from (or elimination of) the worst vehicles, and continuous improvements from the best vehicles. A similar approach could be established for heavy-duty trucks.

Targeted incentives might increase the adoption of advanced technologies. These could be tax reductions for heavy-duty trucks that have certain levels of fuel consumption per unit size or weight, or that possess specific technologies. Such incentives may overcome concerns by truck owners about the reliability of new technologies that are not completely proven.

Creating demand for advanced technology vehicles that promise dramatic reductions in fuel use and CO_2 emissions but are still in testing would be more difficult. A package of initiatives to develop a new market could include:

- Minimum standards for truck design or fuel consumption that are gradually tightened over time, eventually requiring the use of advanced technologies.
- Information campaigns for trucking companies about available or near-term technologies, and the potential benefits of investing in them.
- Price incentives for the purchase of vehicles possessing specific technologies, or for those meeting strict performance criteria. These could be either tax credits or subsidies that would make the vehicles competitive with conventional ones (price *buydown*). Such incentives could also be applied to currently available technologies, such as low-rolling resistance tires[32]. Similarly, fees or sales taxes on new heavy-duty vehicles could be partly based on unloaded vehicle weight, engine efficiency, or tested fuel consumption.
- The development of technology purchase consortia that would form groups of buyers large enough to interest manufacturers in making the investment to produce the technology.

Policy Example: Improving Heavy-duty Truck Efficiency

The literature on the effects of particular policies on heavy-duty fuel efficiency is scarce. Based on the success of the Japanese *top runner*

32. For example, several years ago the United States considered, but did not adopt, a system of fees and rebates applied to vehicle tires, based on tire rolling resistance. The intention would have been to make low-rolling resistance tires more price competitive in the market place, and to encourage tire manufacturers to move in that direction.

program for light-duty vehicles, it appears that a similar program for heavy-duty vehicles could improve truck efficiency by perhaps 1.0% per year in each major truck weight class, or 0.5% above that which would occur without any new policies. This degree of additional improvement is well within the estimated technical potential. By 2010, a top-runner program could improve fuel efficiency for new heavy-duty trucks by 3%-5%, and by 1%-3% for the entire stock of heavy-duty trucks. We project similar improvements between 2010 and 2020, for a total improvement of 6%-10% for new trucks, and 4%-8% for the total stock. Reductions in fuel consumption and emissions of CO_2 would be similar to the stock fuel-efficiency improvements.

Trucking Operational and System Efficiency

The recent emergence of new information technologies has expanded the potential for improvements to freight operational efficiency (or *system efficiency*). IEA's workshop *Improving Fuel Efficiency in Road Freight: The Role of Information Technologies* (IEA, 1999), identified several strategies for improving in-use fuel efficiency (apart from design improvements and capacity increases discussed in the previous sections): the purchase of more efficient vehicles, driver training, vehicle maintenance, fuel management through use of speed governors, etc., dispatching and routing improvements, load consolidation and reductions in truck idling (see box).

Driver Training, Vehicle Maintenance and Other In-use Efficiency Measures

For heavy-duty trucks, driving style is generally acknowledged to be the single greatest influence on vehicle fuel performance. Various studies have estimated that regular training in fuel-efficient driving techniques can yield fuel savings up to 15%-20% per vehicle kilometer. The Motor Industry Research Association in the United Kingdom, for example, found that drivers with fuel economy training were 6% more fuel-efficient on average than untrained drivers (McKinnon 1993).

Relatively few drivers receive proper training on a regular basis. In the United Kingdom, only around 20% of truck drivers were aware of the fuel performance of their vehicles and knew how to minimize fuel consumption. Only 40% of trucking firms surveyed offered training for their drivers more than once every four years. Some did not provide training at all (McKinnon 1993).

For fuel-efficiency training to have a lasting effect, drivers need to be continually reminded. This can be done in a number of ways. One is to monitor drivers' fuel utilization and give them regular feedback on performance. Another is to offer financial incentives in the form of prizes or bonuses. In the United Kingdom, about 20% of trucking firms have some type of driver incentive program. Such programs are just one aspect of the government's *best practice* efficiency program for commerce, which has resulted in significant fuel savings for participating trucking firms (see box).

Several emerging information technologies, highlighted in the IEA telematics workshop, also may help drivers boost efficiency:

- Advanced fuel-economy meters (discussed in Chapter 2 for light-duty vehicles). Many freight trucks are sold with tachographs whose information can be analyzed later for fuel consumption, but not with systems that display data on fuel consumption to drivers in real time.

- Advanced transmissions ranging in level of automation from electronically controlled gearshifts, which leave the driver to select the gear, to fully automatic transmission. A smaller proportion of trucks in Europe has automatic transmission than in North America. Studies show that at a steady speed, an improvement of 10% or more in efficiency can be gained from better selection of gears.

- Future navigation systems. These could take into account road layout, topography, and traffic conditions to determine an optimum

The Role of Telematics: an IEA Workshop

In February 1999, the IEA, together with the OECD and the European Conference of the Ministers of Transport (ECMT), held a workshop to examine how fleet managers and drivers can use new information technologies to achieve organizational and behavioral improvements which reduce fuel consumption in road freight services. It focused on six areas:

- *Fleet fuel management.*
- *Fuel consumption benchmarking schemes.*
- *Routing.*
- *Fuel consumption awareness when purchasing a vehicle.*
- *Maintenance.*
- *Vehicle/driving monitoring.*

Technologies considered included driver information systems; on-board diagnostic equipment to judge vehicle and driver performance, sometimes in real time; and computer systems to improve vehicle allocation, routing efficiency, and even to help in making decisions regarding optimal location of production and distribution centers.

The workshop projected that if such technologies are adopted, fuel consumption and CO_2 emissions in freight transport could decline by the following amount in each area:

- *5% for vehicle technical improvements and purchasing practice.*
- *5%-10% for driving training and monitoring.*
- *More than 10% for other fleet management and logistics measures as a whole. Some companies taking a comprehensive approach improved efficiency more than 20%.*

Fuel savings were found to be just one of many benefits. Cost reductions from system efficiency improvements was among the most important.

The workshop identified possible policies and measures for governments:

- *Increase awareness of available technologies and their potential benefits.*
- *Provide and support training/education programs.*
- *Encourage standardization of equipment and systems software.*

Source: IEA 1999.

speed for a vehicle, which could be set automatically with advanced cruise control. These of course also can be used to determine the shortest and least congested trip routes.

The workshop concluded that each of these strategies could improve fuel efficiency in the medium term by several percent. These technologies are not likely to substitute for fuel-efficient driving skills, and some may be resisted by drivers. Many European truck drivers, for example, prefer manual gearboxes and many dislike cruise control. Overall, it appears that a combination of driver training and use of advanced technologies could improve fuel economy by 10%-15% for any given vehicle but by a lower amount averaged over an entire fleet.

Increasing Vehicle Load Factors and Improved Routing

Just-in-time delivery and increased outsourcing of production of component parts by many companies in the 1990s have probably contributed to increases in total kilometers of travel in many countries, since these trends often require more and longer delivery trips and, therefore, result in lower average truck loadings. However, recent studies point to opportunities for counteracting these trends through improvements in routing patterns and utilization in general. Such improvements could even yield overall reductions in travel and energy use, apart from those resulting from general increases in economic activity. Some data indicate that truck routing and utilization is already improving and will probably continue to do so as advanced logistical systems become more common. McKinnon (McKinnon 1999), in a review of the literature, estimates that the use of available vehicle routing and scheduling software could reduce truck travel 10% on average, and up to 20%. He notes that not all re-routing leads to reductions in fuel consumption, if, for example, the shortest route involves lots of stop-and-go driving.

Fuel economy might improve further if even more sophisticated systems are used to route vehicles, including global positioning systems and other real-time monitors of location that could enable rerouting while the road. Such systems allow for complex routing schemes, employing, for example, more flexible service areas for each truck or even each depot. Routing algorithms are even beginning to employ artificial intelligence, i.e. programmes that incorporate truck delivery experience into the algorithm to optimize it over time. Such technology could enable a two-step routing system of *primary distribution* (from factory to distribution center) and *secondary distribution* (from distribution center to retail outlets).

The Energy Efficiency Best Practice Program in the United Kingdom

The EEBPP is a government-sponsored information and awareness program that aims to stimulate energy savings in industry and commerce, including business transport. In addition to identifying best practices, it focuses on helping companies overcome barriers to achieving efficiency improvements. For freight, the core activity is to produce and disseminate information on potential fuel efficiency. It includes measures such as:

- *Benchmarks that companies can use to measure their performance.*
- *Guidelines that assist organizations to adopt good driving practices.*
- *Case studies that document successes, and highlight the energy, environmental, and cost benefits of these efforts.*

A recent survey of fleet operators indicated that most fleets have taken steps to save fuel in recent years, including driver training, aerodynamic styling, and use of alternative fuels. Fleets that have been actively involved in the best practice program saved about 25% more fuel than those that have not. The survey also indicated that the basic information package has reached most fleets. The project is moving into a new phase involving closer co-operation with trucking companies and industries to identify specific needs and opportunities for fuel savings. One example is a co-operative agreement between truckers and the food distribution sector.

Source: http://www.energy-efficiency.gov.uk/transport/

Truck load factors (or utilization factors), usually measured in ton-kilometers transported per vehicle-kilometer traveled (or by a measure of value per vehicle-km), can be improved in various ways. The most obvious are increasing the capacity for loading of each trip, discussed in the previous section, and optimizing the system of truck dispatching, routing, and loading. Potential improvements include:

- Adoption of nominated day delivery system: delivery firms put vehicles into certain areas on certain days, and clients must request their orders for delivery on those days. This increases the geographic density of the deliveries, but reduces flexibility for clients. This is well-known for home appliance delivery, but has been applied increasingly between distributors and retailers.
- Shifting from a monthly billing cycle to rolling billing: traditional monthly invoicing has encouraged the placement of orders for delivery early in the cycle, and payment later in the cycle. This has, in some cases, caused a bunching of deliveries at certain times each month with slack periods in between. Shifting to real-time billing, through computerized financial accounting systems and electronic linkages, can alleviate this problem.
- Relaxing the requirement for dedicated delivery: during the 1980s and early 1990s, third-party haulage services provided on a dedicated basis for individual clients increased in many countries. However, more carriers are now allowed to carry goods for multiple clients, enabling them to group deliveries and reduce the occurrence of empty backhauls.
- Rescheduling trips to off-peak periods: although many cities require off-peak deliveries, a surprising percentage of truck travel occurs during peak times and congested conditions, which not only slows down other peak-period traffic, but also can substantially reduce the operational and fuel efficiency of freight delivery. As telematics improves, enabling greater tracking of trucks and co-ordination between different points on the supply chain, off-peak travel, including night delivery, is likely to increase in order to improve operational efficiency.

Dutch Programs to Improve Truck Freight Efficiency

NOVEM, the Dutch agency for energy and the environment, manages several programs covering the research and development, testing, and implementation of various ways to save energy and reduce pollution. The project includes a heavy-duty vehicle component that features two main elements:

- *Development of performance benchmarks and performance comparison of different companies.*
- *A methodology and program to assist individual companies in improving vehicle efficiency performance and reducing fuel use.*

NOVEM also assists companies with vehicle purchase decisions and driver training in energy-efficient driving practices.

A related effort helps companies improve operational efficiency by conducting a "scan" of their practices and by identifying solutions. The scan covers:

- *Improvements in truck load factors.*
- *Identification of opportunities to reduce empty return trips.*
- *General improvements in fleet management.*
- *Improved collaboration between shippers and production plants, distribution centers, and receivers.*

Scans from a number of companies indicate that they could reduce travel 10%-15%.

Finally, the NOVEM efforts include making use, primarily on light trucks and delivery vans, of on-board diagnostic equipment and regulators, such as econometers that inform drivers of their fuel consumption rates, speed governors, and cruise control devices. In particular, NOVEM has found that the use of an "Ecodrive" device that limits both vehicle speed and engine revolutions reduces fuel consumption by about 6%. (Most company drivers were not been told and were unaware of the presence of the equipment on the vehicles). NOVEM is now working to provide incentives to vehicle importers to include fuel-saving devices such as econometers and cruise control as standard equipment or low-cost optional equipment on the vehicles they bring into the Netherlands.

Source: NOVEM, http://www.novem.org/novem/home.htm

The Role of Logistics Centers

The basic idea behind the development of logistics centers that coordinate the routing and delivery of goods for multiple firms and different types of goods, is to gain efficiencies from consolidation as well as from *hub and spoke* types of distribution systems, which have revolutionized passenger air travel. For such a system to work, volumes must be high. The more firms that participate and co-operate in using a facility, or a network of linked facilities, the more efficiently it works in terms of larger truck sizes, higher load factors, and fewer empty backhauls – and therefore lower fuel use and emissions of CO_2. Logistics centers can also offer other valuable services to shippers, such as tracking, warehousing, inventory management, repackaging, labeling, order processing, etc. These additional services can help logistics centers to be profitable.

In Germany, *goods transport centers* (GVZ) are playing a growing role in improving freight transport efficiency. Capacity utilization in long-distance traffic for goods shipped through centralized terminals increased an estimated 30% compared to previous patterns, reducing the number of transport operations by approximately 25%. Two distinct types of logistics centers have been identified in Germany (Stabenau, 1996): Designated "intermodal" centers, usually set up by municipalities, are intended to attract various freight transport undertakings like freight forwarders, warehouse keepers, and haulage contractors. This type stresses centralized location more than combining freight from different modes. The other type focuses more on multi-modalism, and usually features transfer capability between road freight, and one or more other modes such as rail, inland waterway, maritime, or air transport. The first type of logistics center tends to be located in or near cities; the latter type is usually located near two or more modes.

Reductions in Empty Running

Reductions in the empty running of trucks can be among the most effective ways to reduce freight energy consumption. A 1% reduction in total truck trips from the elimination of empty runs could result in a

Europlatforms and the "Freight Village" Concept

"Europlatforms", the European Association of "freight villages", was founded in 1991 when the national associations of French, Spanish, and Italian freight villages joined together. It has since added other country associations, as well as various freight villages from countries with no associations to represent them, for a total of around 40 freight villages throughout Europe. Europlatforms defines a freight village as follows:

"A freight village is a defined area within which all activities relating to transport, logistics and the distribution of goods, both for national and international transit, are carried out by various operators. These operators can either be owners or tenants of buildings and facilities (warehouses, break-bulk centers, storage areas, offices, car parks, etc.) which have been built there.

"Also, in order to comply with free competition rules, a freight village must allow access to all companies involved in the activities set out above. A freight village must also be equipped with all the public facilities to carry out the above mentioned operations. If possible, it should also include public services for the staff and equipment of the users.

"In order to encourage intermodal transport for the handling of goods, a freight village must preferably be served by a multiplicity of transport modes (road, rail, deep sea, inland waterway, air).

"Finally, it is imperative that a freight village be run by a single body, either public or private".

Thus the freight village concept is one that integrates all the functions of freight handling and transfer for multiple modes in a single location or area. It includes coordinating these activities in order to maximize transfer efficiency. A strong telematic system or network would seem to be in important part of a successful freight village.

Source: Appendix to the Statute of Europlatforms, http://www.freight-village.com/europlat/

1% reduction in overall truck fuel use and CO_2 emissions for any country[33]. Increased use of telematics has contributed to a decline in empty running in recent years and may continue to result in reductions, though no estimates of the potential for additional reductions in empty running are available. In the United Kingdom between 1980 and 1996, the proportion of truck kilometers run empty declined from about 33% to 29%. McKinnon (McKinnon 1996) found five primary reasons for this improvement: longer truck journeys (spurring an increased desire to return with paying cargo), an increase in the number of drops per trip, the expansion of load matching services, a growth in the reverse flow of packaging material handling equipment, and greater efforts by shippers to obtain loads for return trips or *backhauls*.

Telematics could contribute to reducing empty backhauls by *backloading* (adding a load to a truck making a return trip). McKinnon (McKinnon 1999) finds:

- Electronic load matching: agencies provide electronic clearinghouse services for return loads. Such agencies are increasing their share of the freight market, though from a very low base.
- Electronic client validation: one of the deterrents to backloading with third-party traffic has been uncertainty about the client's financial position, which can be reduced through on-line credit references linked to computerized load matching.
- Electronic monitoring of vehicle activity: in-cab recording devices, supplementing conventional tachographs, that provide operators with a detailed break-down of vehicle performance and activity that could be used to analyze fleet utilization and identify backloading opportunities.
- Vehicle tracking with in-cab mobile data communication: these would allow revision of vehicle schedules and routes while vehicle are on the road. Operators are then able to exploit backloading and load consolidation opportunities that arise on short notice.

33. This can of course vary depending on the sizes of trucks involved and the reasons for the elimination of the empty trips (e.g. it could lead to longer trip distances for remaining trips).

Reductions in Truck Idling

Truck idling for extended periods (i.e. apart from in-traffic idling) has become a major source of fuel consumption for heavy-duty trucks in North America, but appears not to be a major issue in Europe. Stodolsky (Stodolsky 1999) assessed truck idling in North America and identified several reasons why truckers leave their trucks in idle mode for extended periods:

- To keep the sleeper car heated or cooled.
- To mask out noises.
- To keep engine and/or fuel warm in the winter, and/or avoid a cold start.
- Because other drivers do it.

Data on the extent and impacts of idling are poor, but the best available estimates suggest:

- In North America, about 17% of all Class 8 trucks (more than 33 000 lbs. gross vehicle weight) idle all night each night.
- The daily extent of idling varies somewhat by season: about ten hours per day in the winter and 4.5 hours per day in the summer.
- The yearly average per vehicle is 1 830 hours for long-haul vehicles, and slightly less for all heavy trucks.
- Three to four liters per hour are consumed at idle, which amounts to about 7 500 liters per year for long-haul trucks.

Stodolsky identifies a number of alternatives to idling: Direct-fired heaters, auxiliary power units, thermal storage systems, and truck stop electrification. Table 5.2 summarizes the potential benefits, drawbacks, and energy savings associated with each alternative. All cut energy use and CO_2 by at least 40%, reduce required truck maintenance such as oil changes, and substantially reduce costs for diesel fuel. The savings in maintenance measures alone would be USD 0.10-USD 0.15 per hour of eliminated idle. Payback times would be less than one year.

Table 5.2

Alternatives to Truck Idling

Technology	Benefits	Drawbacks	Energy savings / CO_2 reductions
Direct-fired heater	Heating only for cab/sleeper/or engine anywhere, small	Cannot provide cooling, requires battery power	40% reduction in energy use during former idling time, similar reduction for CO_2 (if heater is oil-fired)
Auxiliary power unit	HVAC and power for cab/sleeper, heat for engine anywhere, serves as survival system	Relatively low efficiency, heavier and larger than direct fired heater	80% reduction in energy use, CO_2 (if oil-fired)
Thermal storage	HVAC for cab sleeper only, anywhere	Requires large mass of storage medium	N/A
Truck stop electrification	Power for HVAC, engine heating and auxiliaries, at electrified stops	Would be expensive to provide at all truck stops, requires separate HVAC equipment, expensive	67% reduction in energy use; CO_2 reduction depends on power generation profile

***Note**: HAVC = heating, ventilation and air conditioning.*

Policy Options for Improving Trucking System Efficiency

No single option exists to improve the efficiency of all aspects of the trucking system. Broad programs such as those in the United Kingdom and the Netherlands, however, include many aspects, and represent innovative approaches to working with trucking companies in identifying potential improvements and cost savings. Many trucking companies and operators do not have a good understanding of the fuel economy of their vehicles, attach relatively low priority to improving it, or believe that investments for improving it would not yield an adequate return. The programs addressed each of these problems and perceptions. *Scans* conducted by NOVEM and others identified opportunities for fuel savings as high as 34% and other benefits to the company besides fuel savings.

A government-sponsored package of measures to improve trucking on-road efficiency could include the following elements:

- Creation of fuel-efficiency awareness and motivation campaigns, including government alliances with industry and trade associations, and dissemination of case studies.
- Support for the development and implementation of corporate fuel-savings programs through tax incentives, and of programs to assist companies in conducting *scans*, and/or support for the certification of independent auditors and trainers.
- Requirements that trucking companies and vehicle manufacturers deploy certain available information technologies on heavy vehicles, including various fuel efficiency technologies and on-board diagnostic equipment.

Measures to improve system efficiency by increasing load factors, reducing empty running, and improving overall efficiency could include the following:

- Investment in city logistics systems including advanced driver information systems, co-operative freight transport systems, and public logistics terminals. While national governments do not usually make direct investments in urban infrastructure, they often provide funding for important projects. Improving urban logistical capabilities for the movements of goods merits funding and co-ordination at a national level, to ensure that systems are compatible.
- Incentives to reduce truck idling (or well-enforced regulations to prevent it) coupled with assistance in providing alternative power sources for parked trucks.

Regarding logistics centers, a key role for governments is to co-ordinate their development so that they work more efficiently with firms and with each other, by using, common tracking systems and software, and other forms of standardization. While growth in the development and use of logistics centers in IEA countries has been rapid, there is not yet a worldwide, or continental system of linked centers. The European system appears to be quite fragmented in most places. Stabenau (Stabenau 1996) estimates that a fully functional pan-European system would comprise 300-400 centers – many more than are currently in place.

To complement the logistics centers, governments also need to encourage the nearby development of industrial capacity such as materials handling, production and assembly plants, or, in the case of centers handling finished goods, commercial and retail capacity. Where possible, the centers should be placed near existing developments, to gain the full benefit of land-use economies. Much like encouraging residential and commercial development around mass transit nodes, fostering industrial development around logistical nodes is a job for governments.

Policy Example: Improved On-road Efficiency

The effect of a policy to promote on-road efficiency depends largely on what percentage of trucking companies can be reached, the quality of programs for identifying improvements for each company, and how much money each company is willing to invest in improvements. If in-use fuel efficiency can be improved by 5% for firms that account for 50% of trucking fuel consumption by 2010, total truck fuel consumption and CO_2 emissions would decline by 2.5%. An on-going program might reach 75% of firms by 2020 for a 4% reduction in truck fuel consumption and CO_2 emissions. If the largest firms are targeted first, reaching 50% of fuel consumption would be possible through a smaller number of firms.

Policy Example: Improved Urban Logistics

No studies were found that link improved infrastructure or the provision of better logistics to changes in truck loading factors or reductions in vehicle-kilometers of travel. However, the EC Auto-Oil II Program modeling work (EC 1999) estimated for Athens that if a program increases average load factors for both heavy and light-goods vehicles by 10%, total fuel use and CO_2 emissions resulting from both freight and passenger travel in the area would decline by 2%-3%. This is the net result of a 7% decrease in truck vehicle-kilometers of travel and a slight increase in ton-kilometers, reflecting the movement of more goods due to lower shipping costs. Light and heavy-goods vehicles in Athens account for about 20% of travel, but almost twice this percentage of fuel consumption and CO_2 emissions. If a country can establish a network of city logistics centers in all major urban areas that raises load factors by 10% or otherwise reduces urban truck travel and fuel use by 7%, and if urban freight travel accounts for about one-third of all freight travel, fuel use and CO_2 emissions would decline 2%-3% for all freight travel.

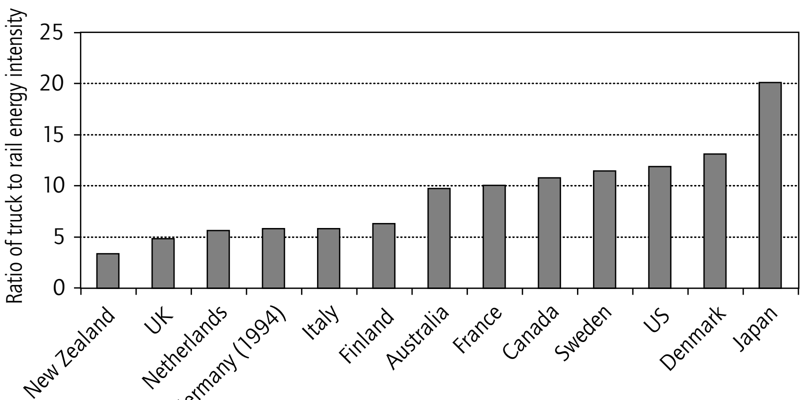
Mode Switching: from Truck to Rail and Water

Rail and boat shipment of goods is substantially less energy intensive than shipment via trucking (see Figure 5.3 above). In terms of energy use per ton-kilometer, freight movement by rail is at least two times as energy efficient as by truck in virtually all IEA countries, and many times greater in some cases (Figure 5.4). There have been many studies of the potential, and many projects to assess and encourage greater *intermodalism* – switching of some freight from trucks to more efficient modes of transport. Though some shifting has occurred in recent years, the potential for much more exists in many countries. On the other hand, rail and water-borne freight transport in many countries currently accounts for such a small share of total surface freight transport that even a major shift would not reduce truck travel or total energy use substantially.

Most countries have excess capacity in rail or water, or both, that could accommodate an increase in the amount freight shifted from truck. But

Figure 5.4

Trucking v. Rail Efficiency: Ratio of Truck to Rail Energy Use per Ton-kilometer of Travel



to reduce truck travel substantially, capacity would have to more than double. In the United Kingdom the rail network only handles 7% of total ton-kilometers; expanding the system to double this figure would be a huge undertaking, but would reduce highway trucking by no more than 10% and result in energy savings on the order of a few percent. McKinnon (McKinnon 1999) estimates that doubling rail freight traffic in the United Kingdom would save less energy than reducing empty running of trucks from 29% to 25%, or increasing the average truck load factor by 10%.

Estimating how much mode switching is feasible or cost-effective is difficult, since the situation of each country in terms of infrastructure, average shipping distances, etc., varies greatly, as do assumptions regarding the responsiveness of industries to price signals and other measures that encourage mode shifting. The potential would also depend on the level of investment made in individual modes and intermodal infrastructure.

Studies for the Netherlands and Germany have outlined plans for large shifts of road freight to rail and/or water:

- The Werkgroep 2000 study described a plan to reduce road freight traffic in the Netherlands by more than half between 1990 and 2015, from 51% of total freight movement to just 21%, with about 80% of the reduction shifted to rail and 20% shifted to water. This is accomplished mainly by increasing the number of combined transport terminals and internalizing the environmental costs of transport, i.e. raising the costs of freight moved by road and lowering costs for rail and water.
- The University of Cologne developed a plan for freight CO_2 reduction in Germany that includes a large shift from trucks to rail, which, combined with an increase in truck load factors, reduces truck travel by 27%. This would be achieved through pricing, increased intermodal terminals, and a relaxation of just-in-time delivery standards.

While rail and boat are substantially less energy intensive than shipment by trucks, any new shifting to rail or water may save less energy than is suggested by looking at the average energy intensities of the different modes. To link road transport to rail or water transport, road feeder movements are often required at one or both ends of the haul, which may require a more circuitous routing of the shipment. Also, since much of the heaviest, densest freight is already moved by rail and water, additional shifts may involve freight of decreasing density, resulting in below-average hauling efficiency.

Given the much higher efficiency of these modes, and their generally much lower cost per ton, why have their shares been declining in many countries in recent years? McKinnon (McKinnon 1996) identifies a number of reasons for the decline in the share of rail freight, which also apply to water:

- Infrastructural: low accessibility of the rail network, lack of depots and sidings, and capacity restrictions on some routes at certain times.

- Financial: high level of fixed costs, and low levels of investment in infrastructure and organization. The intrinsic inflexibility of rail freight operations, and competition between freight and passenger trains for available track slots.

- Pattern of freight traffic flow: short average length of freight haul in many countries, small average consignment size, increasing company requirements for flexible, just-in-time and time deliveries, and poor opportunities for return loading in many cases.

- Changing commodity mix: decline of sectors generating bulk, primary products that have traditionally been moved by rail and boat, and the difficulty of replacing this traffic with higher value traffic in manufactured goods.

- Regulatory framework for intermodal competition: tougher regulations for rail freight in taxation policy, excessive regulatory controls, and infringements of traffic regulations by road haulers (e.g. illegal haulage of goods required to be moved by other modes).

- Industrial experience: negative view of rail freight, rooted in poor service in the past, withdrawal of services, sharp rate increases, strikes, etc.

Policy Example: Freight Shifting from Truck to Rail and Water

This example assumes that at least 5% of freight can be shifted from truck to a combination of rail and water in most countries through a variety of measures, including investments in increasing the capacity of these modes and, in particular, in freight handling and intermodal transfer stations. Since such activities already occur in many countries, this policy would mainly increase the rate or level of government investment in these areas. Increased fuel taxes or travel charges could also be levied on trucks, in part to pay for the intermodal investments. Also, substantial increases in trucking costs may be required to force a substantial shift away from this mode.

Modal Shift as a Centerpiece to Freight CO_2 Reduction Measures in Japan

Japan's current plan for reducing CO_2 emissions includes a package of measures for the freight shipping sector. These improvements are expected to reduce CO_2 emissions from freight by nearly 10% by 2010, representing about 20% of the total CO_2 reduction targeted for the entire transport sector (Horiuchi 2000).

Steps being taken in the freight sector include:

- *Increasing the modal shift from trucks to rail and ships for shipments longer than 500 km from 40% to 50% through better facilities, and new terminals.*
- *Improving the technical efficiency of each mode.*
- *Reducing inland transport distances through the construction of eight new regional gateway ports for containers.*
- *Improving truck load factors by at least 3% (from 47% to 50%) through more company vehicles, joint delivery centers, and increased use of telematics.*
- *Increased use of trailers and larger trucks, involving the deregulation of gross vehicle weight from 20 tons to a maximum of 25 tons for heavy-duty trucks and 20 tons to 28 tons for semi-trailers. Upgrading of bridges and roads to accommodate the heavier vehicles.*

Because Japan is an island country, most freight destinations are within a few hundred kilometers from the water. Thus, most imported goods can be delivered by ship fairly close to their final destination. On the other hand, the short overland trips make train shipment less economical than truck shipment in many cases, as train becomes increasingly competitive with distance. Even in cases where goods are transported longer than 500 km, more than half of these shipments are made by truck.

The Japanese approach is to shift as much freight travel as possible to boats and trains by building new freight terminals at several ports around the country, and increasing the shifting potential between ships and trains through construction of the eight new gateway ports. They should result in a 10% shift from truck to rail transport. The new gateway terminals will also reduce truck travel for many deliveries. Finally, the trucks themselves are targeted to become more efficient and carry heavier loads at slightly higher average load factors.

Source: Horiuchi 2000.

If the energy use in transporting this 5% share by rail or boat is halved (a conservative estimate in light of the much greater differences in average energy modal intensity in some countries) freight fuel use and CO_2 emissions would decline by slightly less than 2.5%, depending on the initial trucking share of total freight movement.

Since, in many countries, the modal shares for rail and boat have actually fallen in recent years, this measure could focus on preventing a further 5% shift to trucking, but would involve similar actions and have similar effects on fuel use and CO_2 emissions.

Reductions in Freight Travel by Reducing Trip Distance

Reducing freight travel by relocating points of freight supply and demand closer together should be possible. This section briefly discusses two possibilities: decentralizing the inventory to put it closer to the customer and/or producer, and shifting the source of products and manufacturing inputs from more local suppliers.

Decentralization of Inventory

Current arrangements of supply and distribution centers are usually designed to minimize cost, and to move toward greater decentralization of warehousing and distribution probably would not be cost-effective for most goods unless fuel prices rose dramatically (McKinnon 1999). This suggests that fuel prices are not especially important in determining locational practices and that using them as a policy to dampen trucking ton-miles of travel may be difficult and expensive. Fuel costs usually represent well under 1% of sales revenue for the average company, even in Europe where fuel prices are high (Touche 1995).

Even if reducing fuel costs is not significant, other benefits could be. Businesses are increasingly recognizing the benefits of locating inventory near the customer or point of production, rather than at a large central location. These benefits can include increased responsiveness to customers, better timing of deliveries (including *just-in-time* deliveries), and reductions in required stock inventories.

Regionalization of Sourcing

Re-sourcing products from long-distance suppliers to nearby suppliers is a longer-term endeavor, as most products are shipped under fixed contracts that can only be changed over time. The cost of shipping itself is not a strong incentive for finding local suppliers. Even large increases in this cost may have little impact. McKinnon states that "in many industries, factor cost differentials are very wide relative to the road transport costs, making it economic to move products long distances for intermediate processing that may only add marginally to the product's value" (McKinnon 1999). As the global economy continues to integrate, the trend in sourcing appears likely to be toward greater reliance on long-distance shipments rather than a shift to shorter-distance shipments.

However, potential energy savings from changing the locations of product sources can be dramatic. In cases where local suppliers exist or where options exist for matching production with nearby distribution and markets, delivery distances can be cut by more than half. For example, Strutyniski (Strutyniski 1994) has shown how *rationalization* of the supply networks of large car assembly plants, involving greater vertical integration at the regional level, could reduce freight transport by 70%. He also acknowledges, though, that spurring such a rationalization would require a fivefold increase in fuel costs. Whitelegg (Whitelegg 1995) has developed a *strong sustainability* scenario for reducing freight fuel consumption in the United Kingdom by 60% in 2025, largely through local sourcing, but it is unclear how this can be brought about.

Policy Example

Because of the uncertainties about the effects of any policies to encourage regionalization and localization of product supply, and the difficulties in designing viable policies to encourage such changes, no policy example has been developed for this area. However, while the difficulties involved in changing supplier/receiver locational relationships are evident, there is reason to continue to assess possibilities in this area in the future due to the large potential fuel savings and CO_2 reductions it appears to offer.

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