CO₂ EMISSION TRENDS AND REDUCTION OPPORTUNITIES
IN TRANSPORT, HOUSEHOLDS AND COMMERCIAL SECTORS

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1. Introduction

What can be accomplished in a decade? To meet the Kyoto targets most countries must de-carbonise faster than ever before. All IEA Member countries have energy policies and programmes that to varying degrees deal with energy diversification, security of supply, economic efficiency and environmental protection. In the last decade, many policies and measures have been developed to reduce greenhouse gas emissions. Nonetheless, additional domestic policies and measures will be needed.

This study looks at existing and potential domestic energy policies and measures that can contribute to fill the gap between the targets set in the Kyoto Protocol and the present trends in CO₂ emissions. The study examines historical trends in carbon emissions and projects these trends for several countries. Building from this, it looks at several technologies that offer sufficient potential to contribute to the closing of the gaps, and identifies selected policies and measures that can stimulate the adoption of these low-carbon technologies in the Kyoto timeframe and beyond. The study is a work in progress that takes a fresh look at existing and potential domestic energy policies and measures that can contribute significantly to greenhouse gas emissions reductions and help meet targets set in the Kyoto Protocol. The study provides a detailed look at individual subsectors in selected countries and estimates the potential for CO₂ reductions in these sectors, and identifies potentially successful policies – both those already implemented in individual countries and those with significant potential that have not yet been implemented. Detailed sectoral reports from this project are being prepared for COP 6.

In the transport and residential sectors, our analysis has so far been focused in two areas: light-duty vehicle fuel efficiency and building shell efficiency. In these subsectors, the analysis focuses on opportunities to adopt technologies that would improve efficiency, rather than reductions in “activity” (levels of travel or average building temperature or area), or other types of structural shifts. In the next phase of analysis, recently begun, the focus will be extended to the potential for non-technology improvements in passenger transport (such as model shifts, driving behaviour, etc.) and is also being extended to the freight sector. In the residential and service sectors, the analysis is being extended to appliances and other opportunities to promote energy efficiency.

1 In this paper the term residential will be used to denote energy use in households, while service sector will be used denote energy use in service and commercial buildings.
Understanding elements behind past emission developments is important when identifying focused policies to reduce future emissions. This understanding is gained by decomposing emission development into factors related to growth in energy service demand and technology factors with the potential to reduce emissions through fuel switching and improved energy efficiency. Knowing how these factors have affected emissions in the past allows for better judging the effects various policies and measures can have on future emissions. Hence an important part of IEA’s Policies and Measure project is to investigate country submitted baseline projections and compare these with both historical developments and each country’s Kyoto target. This analysis is based on IEA’s indicator approach, which is presented in a separate paper.

This paper starts out by presenting trends in CO₂ emissions from transport, residential and service sectors, including a discussion of which factors that impact a country’s CO₂ emissions. This then form as a basis for assessing baseline developments and Kyoto targets for three countries that so far have been analysed in the IEA project. Finally, the paper provides examples of analysis that have been performed for building shell efficiency and light duty vehicles.

2. Transport, Households and Commercial Sectors and the Kyoto Challenge

Without new initiatives, total CO₂ emissions in IEA Member countries are likely to rise more than 30% above 1990 levels between 2008 and 2012. The Kyoto protocol calls for average reductions emission of all greenhouse gases to 5.2% below 1990 levels. Taking emission growth and the Kyoto targets together, IEA Member countries would have to reduce CO₂ emissions by more than 30% from “business-as-usual”. While IEA economies significantly reduced emissions per GDP between 1973 and 1990, this decarbonising trend has slowed markedly in recent years. Renewed economic growth and a slower rate of energy intensity decline pushed up emissions almost everywhere. To meet the Kyoto targets most countries must now de-carbonise faster than ever before.

Emissions from transport, residential and services sectors made up about 42% of total IEA emissions in 1997. The country variance is large, transport emissions range from less than a 15% share to more than 40%, while residential and service sector emissions constituted from about 10% to 40% of countries’ total emissions. If emissions from electricity used in the residential and commercial sectors are allocated to these sectors, the country variation would be even larger; residential and service sector emissions would then amount to approx. 10% in the lowest case, to 53% of total emissions in the highest case.

Figure 1 shows per capita emissions from residential, commercial and transport sectors (travel and freight) for selected IEA countries. Emissions from residential and service sectors include emissions resulting from the electricity used within each sector. The figure shows that for a majority of countries (Denmark, Norway, West Germany, the United Kingdom, and the United States) total per capita emissions from these sectors have not changed much over time. In all these five countries emissions from residential and service have fallen more or less enough to compensate for increased emissions from travel and freight. It should be noted, however, that for some countries part of the fall in residential and service sector emissions is
due to reduced emissions pr unit electricity generated. For the two countries where per capita emissions have increased, Japan and Australia, all four sectors contributed to growing emissions.

The relatively small changes over time for each country shown in Figure 1 are in contrast to the big variations across countries. The US emissions are more than four times higher than in Norway and about 2.5 times higher than in Japan. The share of carbon intensive electricity can explain part of the differences seen in emissions from residential and service sectors. In Norway energy use in these two sectors are dominated by electricity generated from hydropower. In the other countries natural gas use is more prominent, and even if the electricity share is lower than in Norway, power generation is at least partly based on fossil fuels. For example, CO$_2$ emissions per unit of final energy for electricity generated from conventional coal plants are almost six times higher than emissions from the same amount of final energy delivered as natural gas, or about five times as much as when delivered as gasoline to a car. The latter helps explaining why some countries have high emissions from residential and service sectors relative to transport compared to other countries.

**Figure 1**  
CO$_2$ Emissions per Capita for Selected IEA Countries

Comparing Figure 1 with Figure 2 (which shows final energy use per capita by sector) illustrates the impact of differences in fuel mix among the countries. In Figure 2 Norway is third highest after the United States and Australia and Australia (1994/95). In Figure 1, per capita emissions for Norway were the lowest among the countries compared (1994).
3. Seeking Opportunities for Emission Reductions

The variation in CO\textsubscript{2} emission levels per capita (Figure 1) suggests that countries will have significantly different opportunities for emission reductions in the various sectors. A first step in addressing opportunities for emission reduction is to understand why countries differ that much.

As discussed above, part of the reason for the variance in emissions is due to differences in fuel mix. But as Figure 2 showed countries also differ significantly in terms of the level of energy use. Energy per GDP vary by as much as a factor 2.5 across all IEA countries. This alone indicates large differences in emissions.

3.1 Factors Affecting Energy Use and CO\textsubscript{2} Emissions

IEA analysis indicates that more than half of the country-to-country variations in the ratio of energy use to GDP may be due to non-energy factors such as weather and climate, geography, travel distance, home size and manufacturing structure. The rest can be explained from variations in energy intensities (measured as energy per output) in the various end-use sectors. Table 1 illustrates some of the non-energy factors influencing energy use and emissions in residential, services and transport. Differences in energy prices are also shown. Energy prices often reflect non-energy factors like resource base, industrial policy, distributional policies and fiscal reasons.
Table 1

Variations across IEA Member Countries

<table>
<thead>
<tr>
<th>Primary Energy per GDP:</th>
<th>Varies by a factor of 2.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO2 per GDP:</td>
<td>Varies by a factor of 2.5</td>
</tr>
</tbody>
</table>

| Climate:                | Heating degree-days vary by a factor 5 |
| Car use:                | Distance driven per capita varies by a factor 3.5 |
| Freight:                | Tonnes hauled varies by more than a factor 2 |
| Home size:              | Area per capita varies by a factor 2 |
| Service buildings       | Service building area to service GDP vary by almost a factor 2 |

| Energy prices:          | Road fuel varies by a factor 3, |
|                        | Heating fuel by a factor 2, |
|                        | Electricity by as much as a factor 3. |
|                        | The difference between coal and gas price within a country varies by a factor 3 |

These non-energy factors are rarely the primary target for energy and climate policies, and hence it is important to separate the effect of these factors when addressing the impact of policies and measures. Within any one country, factors shaping emissions can be divided into driving forces and technology response options, respectively. The driving forces are related to increased economic activity and more consumer comfort and convenience, all driving up demand for energy services, while technology response options provide opportunities for reducing emissions per unit of energy service provided. The latter can be defined as changes in carbon intensity. Broadly speaking three components affect the carbon intensity:

1) end-use energy intensities,
2) fuel mix in the end-use sectors, and
3) emissions per unit electricity or district heat generated.

The latter component reflects both changes in fuel mix and efficiency of electricity and heat generation. Energy intensities are defined as energy use per output in the various end-use sectors, e.g. space heating per area, energy per person-km travelled, energy per service sector value added, and are closely related to development of energy efficiency. Figure 3 illustrates how CO₂ emissions can be broken down into these different components.

Demand for energy service is driven by factors like population growth, house size, car ownership, distance driven, output of different production sectors, etc. Energy services are thus related to GDP and can be expected to rise as long as countries experience economic growth. Hence, when assessing potentials for various policies and measures it is important to distinguish between the upward driving force growing energy service levels have on emissions and the opportunities for emission reductions offered by improved technology lowering carbon intensity.

In Figure 3 likely areas for energy and emission abatement policies are illustrated with arrows. This includes policies and measures directed towards:

1) more efficient end-use of energy (affecting energy intensities)
2) changes to end-use fuels with less carbon content (affecting end-use fuel mix);
3) improvement of supply conversion efficiency, and moves to renewable energy and low-carbon fuels (affecting emissions per unit electricity or district heat);
4) reduced activity levels, e.g. reduced travel, and changes in the structure of energy use, e.g. improving public transportation (both affecting demand for energy service)

How much have growth in energy service levels driven up emissions historically and how much has falling carbon intensities decoupled emissions from increasing energy service levels? Analysis of historical trends shows that from 1973 to 1990 demand for energy service grew almost at the pace of GDP in most IEA countries. At the same time, rapidly falling carbon intensity reduced emissions everywhere, but at varying degrees (see Figure 4). In some countries reductions were enough to more than compensate for the effect of increased energy service levels, while in others the push for more energy services outweighed the reductions in carbon intensity, resulting in a net increase in emissions over the period. Reduced end-use energy intensities is the main reason for the decline in carbon intensity, augmented in some countries by reduced emissions from electricity and district heat generation.

Figure 3
Decomposition of CO₂ emissions
In the early 1990s recession affected demand for energy service in most IEA countries. Still emissions increased almost everywhere due to significant slow-down in the rates of decline in energy intensities. The most recent trends, with renewed economic growth and a continued slow rate of reductions in energy intensities, show strong increases in emissions most places. This development is alarming given the short time available to reverse the trends in time for the Kyoto target period.

3.2 Future Development: Filling the Gap between Baseline and Targets

What kind of future development of energy service levels and carbon intensity can be expected in the absence of aggressive policy action, and how much more need to be done in order to meet the Kyoto challenge? Consider the following example (Figure 5) where historical development in Danish CO₂ emissions are decomposed into changes in energy service levels and into the factors affecting the carbon intensity: electricity and district heat sector emissions, end-use fuel mix and end-use energy intensities. The historical development is contrasted to a baseline, based on projections recently made by the Danish Energy Agency. The historical development and the baseline is then compared to a “target case”. This case is constructed by IEA and reflects what may have to happen if Denmark is to meet its “EU
bubble” target, without trading or other flexibility mechanisms and also assuming that energy related CO₂ emissions are proportional to the overall target².

As Figure 5 shows Danish emissions decreased between 1990 and 1995, contrary to the development in the previous period. The figure clearly indicates the main reason; emissions from the electricity and district heat generation sharply declined as coal fired condensing capacity was replaced by natural gas, to a large extent used in new combined heat and power stations. Somewhat slower growth in energy service demand and a less carbon-intensive end-use fuel mix also contributed to lowering emissions. However, energy intensities, the main force driving down emissions before 1990, hardly changed at all between 1990 and 1995. In fact without the “dash for gas” in electricity and district heat generation, (and holding all other factors constant), Danish emissions would have increased by approx. 1% per year, rather than the 0.3% reduction that was achieved in this period.

The baseline development up to the year 2000 (adjusted according to statistics through 1997), suggests even stronger reductions in Danish emissions. This is a result of continued reductions in emissions from electricity and district heat generation, but also through a small effect from fuel switching on the end-use side and renewed reductions of energy intensities in the various sectors of the Danish economy. Hence, despite a relatively high growth in energy service demand, Danish emissions are expected fall by more than 2% per year through the year 2000. After 2000 the projected emissions continue to decline, but at a lower pace as the majority of the coal based condensing power capacity has been phased out.

In the target case IEA assumed that both energy service levels and end-use fuel switching would develop as in the baseline. Given the ambitious plan for the electricity and district heat sector embedded in the baseline, this component has also been assumed to follow the projected baseline. This leaves the remaining emission reductions to be achieved through stronger reductions in sectoral energy intensities. Since the baseline emission development is so close to the target, energy intensities only have to be reduced by 0.6% more on average per year between 2000 and 2010 than in the baseline. However, this is much more than the decline in first half of the 1990s, and even more than the levels achieved in the 1973-1990 period.

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² The Danish projections are based on emission numbers corrected for the exchange of electricity with its neighbouring countries. As 1990 was a year with relatively high levels of imports it means that the corrected 1990 figures are higher, and thus the 2010 target less ambitious, than without this correction.
The example for Denmark is based on data for all sectors. Similar analysis could be shown for each main sector. In Figure 6 baseline development for CO2 emissions and energy service demand in services, residential, travel and freight is shown for three of the countries IEA is studying in the Policies and Measure project. The figure shows that the expected growth in energy service levels in the United States is relatively uniform across the four sectors. The growth in travel and freight is higher than in the two other countries, while the energy service levels in service and residential sectors are projected to grow at about the same rates as in Germany. By contrast Denmark expects a very strong growth in energy service levels in the service sector and a low growth in residential.

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3 The US baseline is based on the reference case calculated by the United States Energy Information Agency (EIA) for their study “Impacts of the Kyoto Protocol on United States Energy Markets and Economic Activity”. The German baseline is produced for the German Government by Prognos AG. Data that describe in detail inputs and outputs to the Prognos work were supplied by ISI/Fraunhofer Institute, Karlsruhe. The German baseline is not strictly a “without measure case” as it includes policies under development and/or likely to be implemented in the next few years.
In all countries, and for all sectors, CO$_2$ emissions are expected to increase less (or even decline in some cases) compared to energy service levels, indicating a decoupling through reduced carbon intensities. Both the Danish and the German baselines include a strong shift from coal to gas in electricity generation, leading to significant reductions in carbon intensity for residential and service sectors. In Denmark the total decline in carbon intensity is enough to more than compensate for the growth in energy service demand in both sectors, while in Germany a small net increase in CO$_2$ emissions is still expected in the service sector. Note however, that in the travel sector reductions in German carbon intensity more than offsets the growth in energy service levels driven by increasing mobility, leading to a net fall in CO$_2$ emissions from this sector.

Figure 7 shows the expected declines in the energy intensity components for the same countries’ baselines. The sector intensities are compared to the expected change in intensity averaged for the entire economy in the baseline and in a “target case”. For Denmark the target case is the same as the one described above. The German case is also based on its “EU-bubble” target, while for the United States two target cases are indicated. The “-3%” case reflects what may have to happen if the United States is to meet its Kyoto target only through domestic measures, while the “+24%” case is a scenario where US emissions rise by 24%
between 1990 and 2010, with the remainder of the United States Kyoto commitment covered by emission trading.4

The figure clearly indicates the strong decline in the German travel intensity compared to the other countries. But it is the decline in the German residential intensity that stands out the most, this component alone is expected to drive down emissions in this sector by on average 2.5% per year between 2000 and 2010. In the United States and Denmark only about 1% decline annually is projected in the baseline.

For all three countries the energy intensity in the residential sector is projected to fall more than average for the entire economy. In Denmark and the United States also the service sector intensity is expected to fall more than average, while in the strong decline in travel intensity in Germany exceeds the average of all sectors. It is only the German residential intensity that is projected to fall more than in the constructed target case intensity for the entire economy5.

Figure 7

Changes in Energy Intensities 2000-2010

4 The target scenarios are constructed as “what if” scenarios by the IEA secretariat and do not represent any US Governmental plan. –3% is used as the target in the domestic measure only scenario since the difference between this target and the US Kyoto target (-7% from 1990 level) is assumed covered via measures reducing non-CO2 GHG’s and increasing sinks.

5 Note that the three countries baselines are constructed using very different methodologies and assumptions and are thus difficult to compare directly. For example, the German and Danish baselines contain both implemented and planned measures, which to some extent can explain the rapid declines seen for some sectors in Figure 7.
How can the gaps between baseline developments and the reductions the Kyoto protocol calls for be filled? Fortunately, countries have several ways to achieve domestic emission reductions. Un-exploited opportunities to reduce emissions exist world-wide, notably in more efficient energy use and fuel switching. But time is short, and only the technologies already at the commercial or near-commercial stage today will be available to help reduce emissions in the timeframe 2008-2012. In most sectors, however, energy-using capital turns over slowly, limiting the take up of new technologies in the short run. Hence, to meet the Kyoto targets strong policy action will be required to accelerate technology deployment and enlarge the savings that accrue when new technologies are employed. In addition, policies should promote the deployment of long-term technologies that will provide sustained emission reductions after 2012.

Taking the residential sector as an example, future emissions from this sector depend strongly on how rapid electricity use will continue to grow and how successful policies aimed at improving appliance efficiency will be. There are many measures that can be easily implemented to this effect. Stand-by losses from household and office equipment can be reduced through simple cost-effective technologies and lighting can be easily improved, not only reducing electricity demand but also offering enhanced working conditions and higher productivity. While most appliances are replaced over a 10-15 years time period, the building stock turns over very slowly. Even if this is limiting the short-term potential for reductions advantage should be taken of on-going modification and renewal of existing buildings to ensure that investments in improved energy efficiency is done at the same time. Also, for new buildings prompt action must be taken now to affect building shells that will be around for the next 60-80 years.

An example of a more detailed analysis of how building shell efficiency improvement can reduce emissions in the residential sector is presented in the next section. Further analysis of other policies and measures in this sector is underway in IEA's project on Policies and Measures.

4. CO₂ Reduction Through Building Shell Efficiency Improvements

The first analytical focus of the Policies and Measures Study in the buildings sector has been on space heating and shell efficiency (work on appliance efficiency potential and policy options is now underway). This section summarises the results of the space heating / shell efficiency analysis, and briefly describes policy options for this sector.

Space heating has all but disappeared from the policy agendas of most IEA countries. Many countries assume it was taken care of in the 1970s and 1980s when many countries (most notably Sweden and Denmark) spent the equivalent of hundreds of US dollars per capita on subsidies and grants for insulation. Later, in the 1980s, some utility programmes in the United States targeted the sector. But by the 1990s, heating costs were down, as was the share of the household budget spent for heating. Many analysts lost interest, too, sharing a perception that retrofit, in particular, is expensive as well as inconvenient for individuals and programmatically cumbersome for authorities.

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Nonetheless, in many countries a new national programme of thermal retrofits may be in order. There are several reasons for this: first, there is potential for significant cost-effective reductions in energy use in heating existing homes; second, the distributed nature of the problem – individual existing homes – argues for a large scale programme to achieve economies of scale in production of equipment and insulating material, etc, as well as distribution and installation; third, only the established authorities can undertake the necessary measurement and surveys, to calibrate accurately the present consumption, estimate the potential and measure the results.

4.1 Key Analysis Findings

To illustrate the potential results of improved shell efficiency including potential energy and carbon savings of a retrofit programme, estimates were made for two countries (Denmark and the US) using a variety of “what-if” assumptions for each country. For each, the base case for household sector heating emissions in 2010 is taken from the country’s existing forecast or scenarios. Starting from these results and each country’s ‘low carbon” scenario, it was postulated that a certain share of existing dwellings in each study country can be retrofitted each year. The assumptions about the number of homes that could be retrofitted each year and the savings per retrofit are primarily based on research literature from each country. The resulting reduction in energy use from each instance of retrofit was then estimated. Assumptions about the impact of improved boilers and furnaces are also included in the estimates. Finally, assumptions about future heating fuel mix were made. With these inputs, estimates of future fuel use and carbon emissions from the existing housing stock (and comparisons to the reference case) were made, focusing on the potential CO\textsubscript{2} savings in 2010. The analysis does not explicitly calculate cost effectiveness but it shows how much – or how little – can be accomplished in a limited amount of time. The details behind the analysis are available in a draft IEA report that will be available for COP 6.

The key assumptions for the US and Denmark, and the resulting CO\textsubscript{2} emissions reductions relative to the reference case forecast are shown below in Table 2.
### Table 2

**Summary of Parameters for Target Cases**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>United States</th>
<th>Denmark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Retrofit rate, % of homes</td>
<td>4.5%</td>
<td>5.5%</td>
</tr>
<tr>
<td>Reduction in heating losses per home</td>
<td>30.0%</td>
<td>25.0%</td>
</tr>
<tr>
<td>Reduction in heating losses in new homes</td>
<td>40.0%</td>
<td>25.0%</td>
</tr>
<tr>
<td>Total reduction in stock-wide heat losses, 2010</td>
<td>11.8%</td>
<td>12.9%</td>
</tr>
<tr>
<td>Boiler efficiencies</td>
<td>81.7%</td>
<td>77.6%</td>
</tr>
<tr>
<td>Total reduction in energy use/dwelling</td>
<td>19.8%</td>
<td>22.2%</td>
</tr>
<tr>
<td>Reduction in carbon per unit of energy from fuel switching</td>
<td>7.6%</td>
<td>17.1%</td>
</tr>
<tr>
<td>Reduction in emissions per dwelling</td>
<td>25.9%</td>
<td>35.5%</td>
</tr>
<tr>
<td>Reduction in total CO(_2) emissions</td>
<td>11.4%</td>
<td>27.3%</td>
</tr>
</tbody>
</table>

### 4.2 Key Policy Approaches

While the potential CO\(_2\) reductions are significant, several important factors work against achieving these savings. Foremost is consumer disinterest. Consumers are reluctant to invest in retrofit measures, which may cause them inconvenience while being installed and which may return uncertain economic benefits afterwards. Some of this is related to the stable price of energy, but some is related to real uncertainties over the savings that can be achieved, given other uses for consumers’ funds. Governments may not have the oil shocks and threats of cold winters to generate consumer interest as they did in 1973/4 and 1979/80. Thus it may take large incentives (beyond the economic value to society) to bring about the levels of retrofit posited here.

How can accelerated retrofit scenarios be realised? A National Retrofit programme could be designed that attempts to “awaken” consumers and spur the retrofit supply industry. Since even in those countries that have had active retrofit programs in the past, these programs mostly ended more than a decade ago, a new retrofit campaign will be able to reach many new homeowners and may be a new message even to long-time owners. As for the components of the message, first and foremost would be to encourage energy audits of homes, and the potential savings (in terms of costs) that could be identified from this simple step. Further, housing authorities should consider partially or fully subsidising the costs of these audits (although they are often offered for free anyway by companies that sell retrofit packages). Much more important, and more expensive, is to finance recommended retrofit measures themselves. Home retrofit at the time of home extension or rehabilitation should especially encouraged, as its incremental cost may be quite low and families are already making large expenditures.

For new buildings, there may be significant opportunities to tighten existing building codes to reflect the latest technologies available. To achieve greater savings at lower costs, training of building trade workers, aggressive development and marketing of improved insulation materials and windows, and improvement of heating equipment must occur in the next few years to have an impact in the Kyoto time frame. Finally, a careful measurement programme to measure current heat losses and keep track of savings is always an important element of a
new government initiative of this type. This should include calibration of the present stock, identify the most promising retrofit needs and most promising and economic retrofit packages, and measurement of the results and tracking by type of house, type of retrofit package, etc.

There are many relatively optimistic “potential” studies for saving energy from space heating, yet recent progress in saving has been slow, because of the role of imperfect markets for thermal protection. For most consumers, payback time horizons are short and discount rates high when investing in energy savings in their homes. Inconveniences associated with undertaking retrofits, and lack of knowledge about their likely benefits, boost apparent consumer discount rates to many multiples of the market cost of capital. Further, consumers have little awareness or say over the choices and actions of builders, trades-people, and equipment suppliers. Consumers and most trades have little way of determining which is the “efficient” solution and builders have a strong bias to reduce up-front cost. Indeed, there is often an abject lack of information on the part of the homebuyer, i.e., the practical difficulty of knowing consumption or comparing with reference for “economically correct” level. Thus there is a need for government intervention in this area to improve the functionality of these markets by reducing costs, increasing apparent paybacks, and improving the quality of available information.

Another market barrier is the difficulty of making certain changes to homes. Some options, particularly wall insulation and additions to windows are very expensive in retrofit but relatively inexpensive if done when the house is built or if the walls are being opened for some other purpose. Other actions, like adding loft insulation, may not face such difficult constraints.

Another concern is that few countries perform a thorough household energy consumption survey (covering fuel use, lifestyle patterns affecting fuel use, and current levels of heating/cooling technology and items affecting shell efficiency such as insulation). As a result, it is generally difficult to make reliable estimates about the condition of the stock today, the potential for additional retrofits to reduce fuel use, marginal retrofit costs, etc. For the United States, a regular national household energy survey (Residential Energy Consumption Survey, or “RECS” [Washington: DC United States Energy Information Administration]) supplemented by ample studies of measured retrofit results gives some basis for estimates. The “Five Lab Study” done for the United States Department of Energy in 1997 placed a modest 11% economic potential on savings in existing homes heated with gas, but as much as 23% for those heated with electricity. In new homes they estimate that savings are 8% and 14% greater, respectively beyond present new home practices. A similar study done for the United Kingdom by the Building Research Establishment (BRE) (Shorrock 1995) is consistent with these results for gas heating. That study was based on a good model of the UK housing stock and information on previous retrofits. The last survey and measurement of heating fuel consumption the Danish housing stock was in 1977/8. Since the potential (and costs) for retrofit depend on the starting points – the state of the housing stock and actual consumption – precise determination of potentials and costs for European countries is difficult.

Table 3 summarises some important market failures and barriers preventing consumers from undertaking retrofits on their own. Potential solutions are also outlined.
**Table 3**

**Market Imperfections and Barriers to Improving Efficiency in Heating**

<table>
<thead>
<tr>
<th>Barrier or Market Imperfection</th>
<th>Key Actor(s)</th>
<th>Potential Solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limited Capital for new home purchase</td>
<td>Banks or Savings/Loans and National Housing Financing Intermediaries</td>
<td>Relax mortgage-lending rules to include heat payments etc in calculating loan-worthiness. Provide tax credits for homes with specified efficiency features. Tax credits for new homes using 30% less energy than normal presented in the Clinton FY 2001 budget for the United States.</td>
</tr>
<tr>
<td>Lack of information about a dwelling’s heating properties</td>
<td>Housing Inspection Officials, local trades and construction groups.</td>
<td>Heat inspection (Denmark, mixed results) and divulgence of present occupants heating characteristics at point of sale (California). Home Energy Rating System (HERS). Issue is how much this affects consumer behaviour.</td>
</tr>
<tr>
<td>Uncertainty over retrofit results</td>
<td>Local or national Housing and Statistical Authorities</td>
<td>Repeat and update Sweden’s Hoegskoleprojekt project on large samples of homes to measure real savings from packages of retrofit, etc.</td>
</tr>
<tr>
<td>Slow Pace of Retrofits</td>
<td>Local Banking and Real Estate authorities</td>
<td>Institute a point-of-sale requirement on upgrading, with financing available</td>
</tr>
<tr>
<td>Lack of Attention to energy during ordinary rehabilitation of a structure</td>
<td>Local Banking, real estate, and building code officials.</td>
<td>Loan subsidies; upgrade requirements for obtaining loans or permits for home extension or rehabilitation.</td>
</tr>
<tr>
<td>Landlord/Tenant split (principal/agent)</td>
<td>Local real-estate, building code, and housing authorities</td>
<td>Upgraded thermal requirements for new multifamily housing; point of sale requirements on rental housing; loan bank for landlord/tenant shared costs; individual metering.</td>
</tr>
<tr>
<td>Common Metering of apartments</td>
<td>Apartment or condominium owners or co-ops</td>
<td>Individual meter installation</td>
</tr>
<tr>
<td>Poor equipment selection</td>
<td>National or local heating and building codes officials.</td>
<td>Standards for window systems and heating equipment, outer wall retrofits, heat flow regulation equipment including room thermostats and shunts; required use of heat pumps.</td>
</tr>
</tbody>
</table>

The problem of improving shell efficiency in new homes is somewhat easier to deal with. This is because the incremental costs of improving new homes are considerably less than costs for improving existing homes. Careful studies undertaken for the United States Department of Energy (the “Building America” programme) document that heating and cooling requirements in new homes can be cost-effectively lowered by 30 to 40%, with attendant reductions in energy use and carbon emissions. For Denmark and other countries there is some information relating consumption in new homes to that in existing homes. Currently, Denmark, the United Kingdom, and w. Germany are planning to strengthen their building codes (“push”), but there is no real quantitative measure of what that will mean in terms of energy savings.

Builders often oppose much stronger norms because these add to first costs, which may discourage new home sales. The problem is limits on consumer liquidity, the amount of
money a prospective buyer can borrow. If the “push” of strengthened building codes is combined with the “pull” of economic incentives; this problem can be overcome. The Swedish practice of increasing loans to cover the extra costs of stronger requirements did this, covering through basic housing loans the incremental costs of energy efficiency beyond what was required in building codes. As a result, neither builders nor buyers would see any major economic penalties from increased investment in better thermal properties of new homes. The loan expansions were formulated so as to prevent uneconomically large sums from being spent on measures. The key feature of the overall Swedish effort, as well as the retrofit campaigns mounted by most European countries in the 1970s and 1980s, is that they were routed in the national and local public and private institutions of housing, rather than competing with housing interests in the name of saving energy. This approach should be the cornerstone of continued efforts, which is the case in Denmark today and in many of the key elements of the United States housing and energy programmes.

5. CO₂ Reduction Through Efficiency Improvements in Light-duty Vehicles

Few IEA countries showed significant reductions in carbon intensities for personal vehicle transportation between 1975 and 1995. The growing volume of car travel boosted emissions in virtually all IEA countries. While the technical efficiency of cars improved, consumer preferences for larger, heavier, and more powerful vehicles offset much of the impact of the efficiency gains. Hence, with strong growth in energy services expected from travel, this sector constitutes one of the biggest challenges for meeting the Kyoto targets.

Yet there are many cost-effective fuel economy technologies available to provide significant reductions of greenhouse gas emissions in the light-duty vehicle sector. Many of these technologies can be employed relatively rapidly, early enough to affect emissions by 2010. Some advanced technologies require more development before they are mature. Such “next generation” technologies can potentially provide very large emission reductions after 2010. However, there is a major stumbling block in achieving these reductions: there may be insufficient consumer interest in vehicle fuel intensity relative to other vehicle attributes to bring these technologies into the market, and actually use them for fuel economy improvement, without new incentives.
5.1 Key Analysis Findings

The IEA analysis of light-duty vehicle technology potential has focused on three study countries: Denmark, Germany, and the United States, and identified current technology levels and future opportunities in these countries. Our analysis indicates that the average technological levels of new vehicles in the three countries in 1998 were surprisingly similar. The primary determinant of differences in fuel intensity of new vehicles in these countries is the average size and weight of vehicles sold, with United States consumers purchasing the biggest, heaviest vehicles and those in Denmark the smallest, lightest vehicles.

While estimates of technology costs and benefits are uncertain, our analysis suggests that available technologies that are cost-effective at current fuel prices, and that have not yet been fully utilised in the new vehicle fleet, hold the potential to provide up to a 25 percent reduction in the fuel consumption of new light-duty vehicles by 2010. For Europe, this finding is broadly consistent with the stated goals of the European vehicle manufacturers’ (ACEA) commitment to the European Union to improve fuel economy - suggesting that the goals of the agreement appear to be feasible, and could be met at relatively low financial cost to consumers (after taking into account fuel cost savings from more efficient vehicles). As new, more efficient vehicles enter the fleet, the estimated CO\textsubscript{2} emission reduction potential for all light duty vehicles by 2010 could be as high as 20 percent relative to what 2010 emissions would be in a “constant technology” case (with no additional market penetration of fuel economy technology).

Figure 8 shows the estimated CO\textsubscript{2} reduction potential for Denmark, Germany and the United States, as a set of scenario forecasts through 2020. The first scenario (top line in each figure) reflects the “constant technology” case, where fuel economy technology is held at its 2000 levels; in this case CO\textsubscript{2} would rise roughly at the rate of travel growth. The second line represents a “reference” case where technology that is cost-effective at current fuel prices in each country is used to its full benefit, taking into account constraints on the rate of uptake of new technology, such as vehicle product cycles. The third line reflects a “constant attributes” case in which, in addition to the use of cost-effective technology, vehicle attributes (acceleration, weight and size mix) are held constant at their year 2000 levels throughout the forecast. The difference between the reference case and the constant attribute case represents potential GHG reductions “lost” to other vehicle improvements. Finally, the bottom line shows the effect of adding additional fuel economy technology beyond the reference case, that which is cost effective up to a CO\textsubscript{2} value of US$100 (on top of current fuel prices in each country). This scenario also holds other vehicle attributes at their year 2000 levels.

As these figures show, there is the potential for significant CO\textsubscript{2} reductions from the uptake of technology in each country, but there is much more potential from adding technology and from limiting the changes in vehicle attributes after 2000. An analysis of potential consumer purchase shifts across vehicle size classes, and demand for more powerful vehicles, however, indicates that half or more of the fuel consumption reductions from new technology could be lost to increases in vehicle horsepower, size and weight. Such shifts would also translate into a loss of a similar magnitude in the potential CO\textsubscript{2} emissions reductions. Thus consumer purchase patterns, and producers’ efforts to accommodate consumer demand by reconfiguring vehicles, are potentially a key obstacle to maximising the potential CO\textsubscript{2} emission reductions from fuel economy improvement. While there have been several
important policies put in place in recent years to promote fuel economy, such as the European Union voluntary agreement with European car manufacturers, it will likely take new policies to ensure that the full benefit of both of these factors is realised.

5.2 Key Policy Approaches

While there are other policy options for reducing emissions from the transport sector, such as modal shifts and enhanced public transportation, this segment of analysis has focused on opportunities for improved vehicle fuel efficiency. In order to maximise the potential contribution of improved vehicle fuel economy to meeting the Kyoto targets, then policies are needed to accomplish three things:

- Encourage manufacturers to use available technologies to reduce fuel intensity rather than increase size, weight and power of vehicles;
- Sharpen the distinctions between more efficient vehicles and less efficient ones to affect consumer choice at the time of purchase;
- Encourage manufacturers to deploy advanced technologies by reducing investment risks and encourage consumers to purchase them by reducing initial costs.

In particular, IEA has identified and analysed two promising policy options that have not yet been widely utilised: fuel consumption-based vehicle purchase fees (or combinations of fees and rebates, called “feebates”) and market incentives for the uptake of advanced “next generation” technologies. The assessment of these policies shows how they could be implemented without new taxes (but instead through tax reform), and how there are excellent opportunities for undertaking such reform.

Key policy findings include:

- Implementation or conversion of vehicle purchase fees (or feebates) to a fuel consumption basis can provide a strong signal to consumers and producers to improve fuel economy, even at quite modest levels. For example, US$250 reduction in fee for each litre per 100 km of lower fuel consumption) could provide as strong a price signal to consumers to switch vehicles as a fuel tax increase of US$0.20 to US$0.25 per litre (based on typical consumers’ relatively high discount rates for future fuel savings).
- Current vehicle purchase taxes in the study countries (and in virtually all Annex I countries) are based on an *ad valorem* approach, and therefore essentially tax fuel economy improvements as well, since most fuel economy improvements applied by manufacturers cost something and therefore raise the price of the vehicle.
- Countries such as Denmark and Germany, with significant vehicle purchase taxes already in place, could convert some or all of these taxes to a fuel-consumption basis and eliminate this tax penalty on fuel consumption. More importantly, shifting to a consumption-based system would send a powerful signal to consumers to shift to vehicles...
of lower fuel consumption. In addition, for large-market countries such as Germany, send an equally strong message to manufacturers to improve the fuel economy of the vehicles they offer. For Denmark, the existing vehicle purchase tax is so high that even if only a part of the tax were converted to a fuel consumption basis, this tax could easily be set as high as $1 000 per litre per 100 km, creating a several thousand dollar tax difference between the most and least efficient vehicles within each size class (see next bullet).

- Even within size-classes of vehicles there is generally a wide range of fuel economy levels, with the worst vehicles typically using 50% or more fuel per kilometre than the best vehicles (up to 100% including diesels). Probably the main issue in exploiting within-class opportunities is lack of consumer information and awareness of this wide range.

- “Next generation” technologies such as hybrid-electric vehicles and fuel cells could by themselves provide substantial CO₂ reductions in the 2010 time frame, and certainly by 2020. However, consumers and producers will need strong encouragement to adopt these technologies on a reasonably large scale and in a timely manner, since the technologies are not yet cost-effective. Policies that help offset the costs of new technologies can provide two benefits: a reduction in technology cost from learning and economies of scale, and a more rapid acceptance of them by risk-averse consumers and producers.

- One existing example of next-generation technology incentives can be found in Japan, where there is a price incentive on the order of $3,500 per vehicle for hybrid-electric vehicles. This has contributed to Japan becoming the first country with significant sales of these advanced technology vehicles. A similar, and perhaps more ambitious, proposal has recently been put forward in the United States. The current Administration has put before Congress (as part of its Climate Technology Initiative package of budget proposals) a tax incentive for electric, electric hybrid and other high efficiency vehicles that would provide up to a $4 000 tax credit for their purchase, with the tax credit increasing in proportion to the fuel economy of the vehicle (compared to conventional vehicles of a similar size).
Figure 8

CO₂ Emissions Reduction Potential in Three Countries

**Danish Light-duty Vehicle CO₂ Emissions: Comparison of Cases**

**German Light-duty Vehicle CO₂ Emissions: Comparison of Cases**

**US Light-duty Vehicle CO₂ Emissions: Comparison of Cases**