Tyndall Centre
for Climate Change Research

# How can we reduce carbon emissions from transport?

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June 2004

Tyndall Centre for Climate Change Research Technical Report 15

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Tyndall Centre Technical Report No. 15

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This is the final report from Tyndall research project IT1.7 (How can we reduce carbon emissions from transport?). The following researchers worked on this project:

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## 1. INTRODUCTION

### 1.1 Context

Climate change is an internationally recognised problem. Carbon dioxide is the most important greenhouse gas and is projected to account for around 70% of radiative forcing of climate by the end of the century (IPCC, 2001a). The United Nations Framework Convention on Climate Change (UN FCCC) was agreed in 1992 and at Kyoto in 1997 developed countries agreed to targets which will reduce their overall emissions of six greenhouse gases[a] to 5.2% below 1990 levels over the period 2008-2012. The UK Kyoto commitment is a 12.5% reduction. The UK also has a domestic target of a 20% reduction in carbon dioxide emissions below 1990 levels by 2010 (DETR, 2000a). The 2003 Energy White Paper (DTI, 2003a) accepts the need for deeper cuts of 60% by 2050.

Transport has potentially an important role to play in achieving reduction targets. In the transport sector $CO_2$ accounts for 96% of greenhouse gas (GHG) emissions. The transport sector is the third largest source of carbon dioxide emissions in the UK and as Table 1 shows the only sector where emissions are expected to be higher in 2020 than in 1990.

**Table 1.1: Greenhouse Gas Emissions by End User (MtC)**

| Sector | Baseline (1990) | 2000 | 2010 | 2020 |
|---|---|---|---|---|
| Business | 90.6 | 68.6 | 64.0 | 64.9 |
| Transport[1] | 39.7 | 41.5 | 47.8 | 52.9 |
| Domestic | 46.6 | 42.7 | 41.5 | 42.6 |
| Agriculture, forestry and land use | 24.8 | 21.6 | 19.1 | 18.0 |
| Public | 10.0 | 8.5 | 7.8 | 7.8 |
| Total | 211.7 | 182.9 | 180.2 | 186.2 |

[1] Including emissions from domestic air travel

The impacts of international aviation emissions are not considered here for two main reasons: (i) the studies reviewed which explore scenarios for future emissions do not consider international aircraft emissions as they are beyond the scope of current climate change agreements; and (ii) many aspects of air transport are subject to international treaties and agreements, and for this sector it is likely that the path to a solution will be through international negotiation rather than action at national, regional and local levels as may be the case for other transport modes. Current emissions attributed to UK international flights are around 8MtC, as opposed to 1MtC for domestic flights (DTI, 2003a), while $CO_2$ emissions attributed to international aviation have increased by 87% between 1990 and 2001 (Baggott et al 2003). Further rapid increases are forecast, to between 18 and 20MtC by 2030 (DfT 2002), posing a serious challenge for a low carbon transport strategy.

Work for the European Commission (Blok et al, 2001) suggests that the role of the transport sector in meeting the Kyoto targets for the European Union will be limited as reductions in other sectors are more cost effective. Thus if a least cost reduction strategy were pursued, emissions from the transport sector would rise in absolute terms, achieving only a 4% reduction from the 2010 baseline forecast through efficiency improvements. Transport would then be the second largest sectoral emitter in the EU after energy. In considering deeper cuts to 2050, transport would have to play a role.

Current UK transport policy aims to reduce emissions of GHG's from transport by 5.6 MtC below trend by 2010. This would leave emissions from the sector slightly above 2000 levels. This reduction is dependent on two key policies: the voluntary agreement between the European Commission and European car manufacturers to reduce average carbon dioxide emissions from new cars to 25% below

[a] The six greenhouse gases are carbon dioxide, methane, nitrous oxide, hydroflurocarbons, perflurocarbons, and sulphur hexafluoride

1995 levels by 2005 (ACEA/EC, 1998), and the Government's 10 Year Plan for transport (DETR, 2000b). In the longer run demand for motorised modes of transport is expected to increase and in the absence of further efficiency gains or developments in low carbon technologies for transport, emissions would then be expected to rise. The key questions for this paper, are by how much are emissions likely to rise by 2050 and how will transport perform relative to other sectors in a carbon constrained (or unconstrained) world. Transport's share of $CO_2$ emissions has been increasing to its current level of 26%, how much further will this figure rise?

### 1.2 Project Objectives and Overview

This is the final technical report of the project "Behavioural Response and Life Style Change in Moving to Low Carbon Transport Futures" funded by the Tyndall Centre for Climate Change Research. The project objectives are stated below:

1. To determine targets for $CO_2$ reduction in the UK transport sector and within this specifically for personal land based transport
2. To develop transport/land use strategies designed to deliver a range of carbon reduction targets.
3. To develop a survey instrument to explore the adaptation strategies of households in response to the measures identified in (1) in order to meet short run and long run targets for carbon reduction.
4. To implement the survey methodology on an experimental basis
5. To analyse household preferences for adaptive strategies and how this response is influenced by specific policies, in order to identify those policies that would be most likely to move society towards a low carbon transport future, at the least perceived cost to households and that are most acceptable.

The first objective was not specified in the proposal but is implied. The project focuses on personal land based transport as this area is the largest contributor to $CO_2$ emissions within the UK transport sector and trends towards increased use of personal motorised transport show little signs of abatement. Moreover this is an area where the issue of behavioural change is perceived to be particularly intractable.

This report is structured to address the objectives consecutively, as was the project. Chapter 2 reviews the literature on appropriate target reductions in $CO_2$ emissions to secure stabilisation at sustainable levels and then examines various scenario building exercises in the UK in order to determine a likely role for transport in contributing to a reduction target. Chapter 2 addresses objective 1 and provides the targets that form the basis for the rest of the project. In Chapter 3 we develop strategies that could enable the personal land based transport sector to meet these targets. The strategies and the behavioural response to them are based on our best knowledge from the literature on response to policy measures and on consultation with experts. Chapter 3 addresses objective 2 above and enables us to move on to explore the feasibility and acceptability of such strategies with households, as reported in Chapter 5. Chapter 4 explores the same strategies and targets but with an expert audience through a Delphi survey. Chapter 5 reports the development of a computer based survey method designed to explore households ability to reduce carbon emissions through changes in travel behaviour. The results of the experimental implementation of this survey are reported. Chapter 5 addresses objectives 3, 4 and 5. Chapter 6 brings together the results from the various phases of the projects in order to draw policy conclusions and identify areas for further research.

## 2. DERIVATION OF TARGETS[b]

The aim of this first phase of the project was to establish appropriate $CO_2$ emissions targets for the UK transport sector by 2050. This was determined by looking firstly at the degree of consensus on appropriate stabilisation levels for atmospheric GHGs by 2050 and secondly by examining studies that have put forward scenarios for $CO_2$ emissions in the UK for 2050 for carbon constrained and non-carbon constrained futures. The level of transport emissions within these scenarios and the ways in which reductions in transport emissions are achieved are used to guide the construction of future targets for the transport sector.

### 2.1 Targets

The UN FCCC has stabilisation of atmospheric GHG levels as its ultimate objective, but does not define a stabilisation concentration, and neither does the Intergovernmental Panel on Climate Change (IPCC). The political, economic, ethical, social and scientific issues that need consideration make defining a stabilisation target difficult. However, examination of the literature shows key themes and preferences for certain target levels and these are outlined below. The emphasis is on the targets of 350, 450 and 550 ppm.

An upper limit of 550 ppm carbon dioxide has been advocated by both the European Commission (EC, 1996) and the Royal Commission on Environmental Pollution (RCEP, 2000). This recommendation refers solely to carbon dioxide though it is acknowledged that other greenhouse gases are also important contributors. Since industrialisation the increase in the concentration of other greenhouse gases has contributed the equivalent of 50 ppm carbon dioxide (RCEP, 2000).

The IPCC (2001a) state that stabilisation of carbon dioxide equivalence (including other GHGs) at 550 ppm would result in a temperature change greater than $2.0^0$C. The WMO/ICSU/UNEP Advisory Group on Greenhouse Gases (Rijsberman and Swart, 1990) state that a $2.0^0$C increase in temperature is a high risk situation and that "temperature increases beyond $1.0^0$C may elicit rapid, unpredictable, and non-linear responses that could lead to extensive ecosystem damage". Arnell et al (2002) compare the impacts of stabilisation at 750 ppm and 550 ppm with unmitigated increases in $CO_2$ and conclude that stabilisation at even the lower level, while reducing future water stress, is still likely to lead to increases in populations at risk from hunger and malaria.

The Global Commons Institute (GCI) (2002) view is that given the state of uncertainty as to the appropriate target level it would be unwise to set the level too high as this would 'lockout' lower target levels. They suggest that if a target of 550 ppm were set, but later evidence pointed to a much lower target of 350 ppm, this would not be achievable after 2005. However, if the initial target was 450 ppm, then this could if necessary be switched to 350 ppm up to 2015. The GCI (2002) believe that 350 ppm is a desirable target and if this were implemented then there is a good chance that "large-scale damage to the world economy, human lives and natural ecosystems can be averted". It regards 450 ppm "as an upper limit for consideration, under which there is a chance that damage, though serious, will be containable".

Others arguing in favour of lower limits include Azar and Rodhe (1997) who suggest that stabilisation of carbon dioxide should be achieved in the 350 ppm to 450 ppm range. They recognise that policies are also needed to constrain emissions of other greenhouse gases. Alcamo and Kreileman (1996) state that "stabilising carbon dioxide alone in the atmosphere below 450 ppm substantially reduces climate impacts", and that controlling non-$CO_2$ emissions (i.e. other GHGs) in addition to $CO_2$ emissions is an effective policy to slow temperature increase.

[b] A version of this chapter, Tight et al, has been submitted to Global Environmental Change.

Houghton (1997) initially examines carbon dioxide stabilisation alone and highlights the economic considerations, recognising that stabilisation below 400 ppm would require an immediate drastic reduction in emissions, and this would come at a high economic cost, which is considered to breach the UN FCCC (United Nations, 1992) requirement for "economic development to proceed in a sustainable manner". Stabilisation in the range from 400 ppm to 550 ppm is recommended.

To summarise, the most common stabilisation target is 550 ppm carbon dioxide. It is generally recognised that additional measures will be needed to reduce other non-$CO_2$ greenhouse gases. If non-$CO_2$ greenhouse gases are also included then the 'safe' target for carbon dioxide alone would have to be lower than 550 ppm. It was therefore decided to use both the 550 ppm and the 450 ppm stabilisation levels in developing the targets used here for the transport sector.

However it is not just the stabilisation target that is the subject of much debate. Other important connected issues include the expected role of different countries and the timescales the reductions should operate on.

## 2.2 The Contraction and Convergence Approach

The Contraction and Convergence approach aims to reduce greenhouse gas emissions to an acceptable level. It is a two stage process: firstly convergence would occur, that is the emissions levels of the developing nations would rise, and emissions levels of developed countries would fall until an agreed point for convergence was reached. At this point all countries would have the same per capita emissions. Secondly all countries would reduce their emissions levels (contraction) to an appropriate sustainable level. International negotiations would determine the upper limit of the concentration of greenhouse gases, and the date when convergence would occur. A significant party in the promotion of this approach is the GCI (2002).

The RCEP used the contraction and convergence approach to estimate the level of reductions that would be required in the UK by 2050 and 2100 for different upper limits of carbon dioxide concentration. The reductions required for stabilisation at different levels are shown in Table 2.1.

**Table 2.1: Contraction and Convergence: implications for UK carbon dioxide emissions**

| Maximum atmospheric concentration ppm | Permissible UK emissions in 2050 (% of 1997 level) | Permissible UK emissions in 2100 (% of 1997 level) |
|---|---|---|
| 450 | 21 | 11 |
| 550 | 42 | 23 |
| 750 | 56 | 47 |
| 1000 | 58 | 61 |

Source: RCEP, 2000

This shows that in order to stabilise $CO_2$ at 550 ppm, emissions would have to be reduced by almost 60% from 1997 levels by 2050 and by almost 80% from 1997 levels by 2100. The RCEP therefore recommended that "the Government should now adopt a strategy which puts the UK on a path to reducing carbon dioxide emissions by some 60% from current levels by about 2050" (RCEP, 2000).

The Inter-departmental Analysts Group (IAG) (2002) has used the contraction and convergence approach to explore the role of other countries. This is shown in Figure 2.1. A key point is the 80% reduction that would be expected from the USA given the high current levels of emissions from that country.

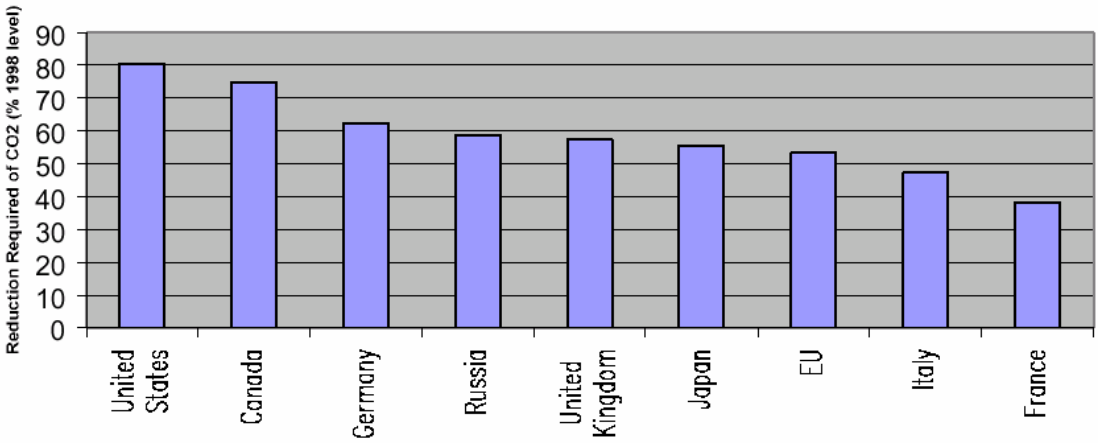



**Figure 2.1: $CO_2$ reductions required by 2050 to achieve stabilisation at 550 ppm (Source: IAG, 2002)**

The RCEP (2000) recognises that some developed nations may be wary of this approach because it involves very large reductions in their emissions, and suggests the introduction of greater flexibility to allow countries to trade their emissions quotas. However any form of trading needs to be 'transparent, monitored and regulated' and backed by enforceable penalties if nations emit more than their entitlement.

The likelihood of other countries adhering to the contraction and convergence approach will be an important consideration for the UK Government in deciding whether or not to follow such an approach. The Energy White Paper (DTI, 2003a) indicates that the UK government has now adopted the 60% target as an aim. However, the PIU (2002) states that greenhouse gases are global pollutants and that the UK should not incur abatement costs, and risk harming competitiveness, unless other countries are also willing to do so.

In this paper the RCEP targets of roughly 60% and 80% reductions for the targets of 450 and 550 ppm in 2050 shown in Table 2.1 have been used. There are several reasons for this. Firstly the stabilisation targets of 450 ppm and 550 ppm are those with greatest support in the literature. Secondly contraction and convergence has substantial political and scientific backing. Thirdly, since this work focuses on the UK, there is a need for UK based targets. Fourthly the RCEP is a long established, influential body, and these target figures are already being used in policy work for the UK. Hence the use of these figures will ensure consistency and enable comparison. In addition, even if the contraction and convergence approach is not followed, the emissions reductions required for the UK are likely to be substantial.

### 2.3 Scenarios

Five recent studies are reviewed here, each of which has utilised the RCEP recommendation of a 60% reduction target. Each provides some indication of the role that transport is expected to play. The studies acknowledge the difficulty both in predicting future change in the transport sector and in developing effective measures which will help sufficiently with current emissions trends. Naturally, given the need to forecast to 2050, the studies make a number of heroic assumptions about future conditions. It is important to note that the emissions examined in these studies are those covered by international agreements and hence exclude the majority of emissions from the air transport sector. The five studies are:

- The RCEP (2000) Twenty Second Report: Energy the Changing Climate.

- The Carbon Trust (2001): Draft Strategic Framework[c].
- The Policy and Innovation Unit (PIU) (2002): The Energy Review.
- The Interdepartmental Analysts Group (IAG) (2002): Long Term Reductions in Greenhouse Gas Emissions in the UK.
- AEA Technology (2002): Future Energy Solutions from AEA Technology in collaboration with the Imperial College Centre for Energy Policy and Technology (ICCEPT): Options for a Low Carbon Future[d].

All of the studies recognise the need for substantial change in order to achieve a 60% reduction in carbon dioxide emissions by 2050. The Carbon Trust (2001), the RCEP (2000), and the IAG (2002) all develop scenarios to show how a 2050 world may look. The PIU (2002) use the Foresight (1999a) scenarios as the base for their work. The IAG and the AEA Technology/ICCEPT collaboration also consider the Foresight work. The Foresight scenarios were developed in 1999 by the DTI in cooperation with SPRU (Foresight, 1999a). There are four scenarios: World Markets; Provincial Enterprise; Global Sustainability; and Local Stewardship. The scenarios are set within the context of two dimensions of change: social values and governance systems, with social values forming the X axis and governance systems forming the Y axis (see Figure 2.2). There is no business as usual scenario but the World Markets scenario could be considered to most closely resemble conventional development.

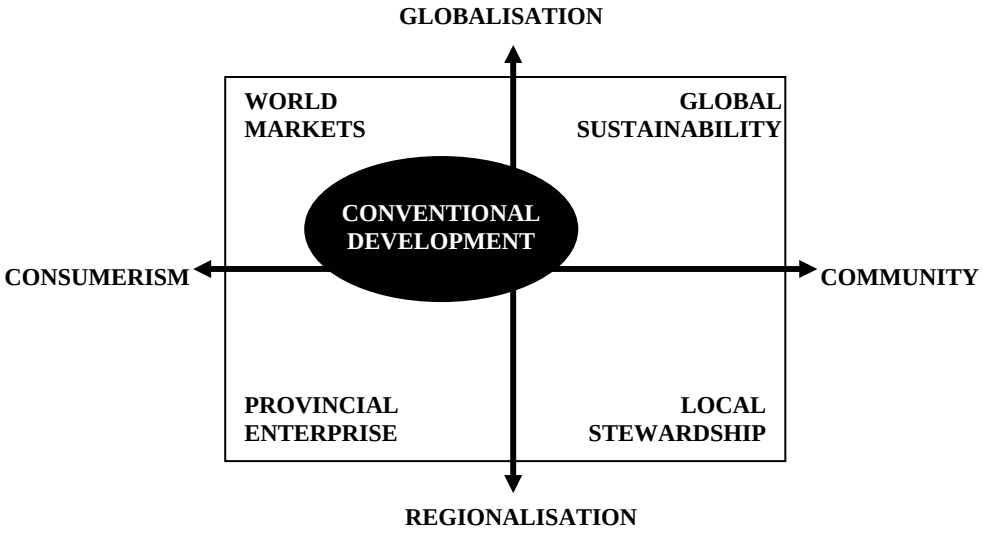



**Figure 2.2: Four Contextual UK Futures scenarios (Source: Foresight, 1999a)**

Foresight (1999a) provides a synopsis of the key themes of the four scenarios:

- World Markets is "a world defined by emphasis on private consumption and a highly developed and integrated world trading system".

- Global Sustainability is "a world in which social and ecological values are more pronounced and in which the greater effectiveness of global institutions is manifested through stronger collective action in dealing with environmental problems".

- Provincial Enterprise is "a world of private consumption values coupled with a capacity for lower level policy-making systems to assert local, regional and national concerns and priorities".

[c] The Draft Strategic Framework is used rather than the Strategic Framework since information about the scenarios and baseline projections is provided in greater detail

[d] The AEA Technology/ ICCEPT work examines three emissions targets: a 45%, a 60% and a 70% reduction from 2000 levels.

- Local Stewardship is “a world where stronger local and regional governments allow social and ecological values to be demonstrated to a greater degree at local level”.

Table 2.2 summarises the varied roles transport is expected to play by the five different studies to achieve a 60% reduction. Table 2.2 includes only those scenarios that yield a reduction in $CO_2$ emissions of 60% or more. It is noticeable that there are differences in both the magnitude of the expected role and the combination of the different measures used to achieve the reduction.

**Table 2.2: Transport Scenarios**

| Study and baseline | Baseline transport emissions MtC and share of total % | Changes to transport demand and supply | Total Emissions 2050 MtC | Transport Emissions 2050 MtC |
|---|---|---|---|---|
| RCEP | 38.8 (26%) | Scenario 1: efficient vehicles, switch to fuel cells<br>Scenario 2 and 3: 25% reduction in transport energy demand through use of fuel cells, increased public transport use, changing lifestyles, use of telecommunications.<br>Scenario 4: 33% reduction in transport energy demand. | 59 | Scenarios 2 to 4 imply a slight increase in transport's share of emissions. |
| Carbon Trust Baseline 1 | 60 (41%) | Low carbon future, savings of 8.4MtC from fuel cell efficiency and 14.96MtC from sourcing $H_2$ from renewables | 46.64 | 36.64 (78.6%) |
| Carbon Trust Baseline 2 | 43 (36%) | Low carbon future, savings of 6.82MtC from fuel cell efficiency and 14.96MtC from sourcing $H_2$ from renewables | 37.26 | 21.22 (56.9%) |
| PIU no baseline | | Global Sustainability and Local Stewardship both could reduce emissions by up to 30MtC through increased efficiency, land use changes, increased use of public transport and non-motorised modes | 55 | 25 (45.4%) GS<br>22 (40.0%) LS |
| IAG | 59 (41%) | Technology leading to the use of low carbon fuels, congestion grows, no new road building, saturation of car ownership and reduced rail fares. | 62 | 36 (58.1%) |
| AEA BAU | 43 (37%) | A 60% reduction involves 87.8% $H_2$ fuel cells<br>A 70% reduction involves 98.0% $H_2$ fuel cells | 60<br>45 | 16 (26.7%)<br>13 (28.9%) |
| AEA World Markets | 52 (39%) | A 60% reduction involves 90.7% $H_2$ fuel cells<br>A 70% reduction involves 98.6% $H_2$ fuel cells | 59<br>45 | 20 (33.9%)<br>12 (26.7% |
| AEA Global Sustainability | 34 (34%) | A 60% reduction involves 74.2% $H_2$ fuel cells<br>A 70% reduction involves 83.8% $H_2$ fuel cells | 59<br>45 | 20 (33.9%)<br>12 (26.7%) |

The RCEP (2000) develops four illustrative scenarios all of which are designed to reduce emissions by 60% (save scenario 1 which achieves 57%) through changes in energy supply and demand. In scenario 1 demand for energy stabilises at 1998 levels. A 57% reduction in $CO_2$ emissions is achieved by switching to less carbon intensive energy sources including 50% of energy from renewables and/or nuclear or fossil fuels with carbon sequestration. In scenarios 2 and 3 demand falls by 36% encouraged by energy efficiency measures and increases in energy prices. Scenarios 2 and 3 differ only in terms of the energy mix required to deliver them. Scenario 4 sees a fall in demand of 47% and no nuclear power or carbon sequestration. The report states that "It is difficult to see how energy demand reductions on this scale could be achieved". The RCEP scenarios examine sectors in terms of energy demand reductions.

The Carbon Trust (2001) use two baseline projections from which reductions are estimated. Baseline 1 is close to a business as usual scenario but still foresees increases in energy efficiency and 15% of electricity from renewable sources by 2050. Emissions would be close to current levels at 150MtC. Baseline 2 sees a greater focus on efficiency and renewables and some constraints on the transport sector, resulting in emissions of 120MtC. Four possible scenarios are considered involving low carbon markets, government, consumers and futures. Only the low carbon futures scenario (which combines the other three in order to remove all the main technical, economic, regulatory, institutional and behavioural constraints), achieves a reduction at or above 60%, namely 72% for Baseline 1 and 79% for Baseline 2.

The remaining three studies make use of the Foresight futures outlined above. The PIU (2002) study does not have a baseline as such. For the purposes of this paper the World Markets and Provincial Enterprise scenarios, in which carbon emissions increase, have been used as the baselines. The Global Sustainability and Local Stewardship scenarios both achieve reductions in excess of 60%, while the World Markets scenarios see a massive rise in emissions from transport. The IAG (2002) baseline includes the measures outlined in the UK Climate Change Programme. They do not forsee a 60% reduction in emissions under any of the Foresight scenarios. They therefore sought to find a prescriptive route to such a reduction, which involved: efficiency savings, 40% renewables, all power generation carbon free by 2050 and both technical changes and reduced demand in the transport sector. AEA Technology (2002) used a business as usual baseline together with World Markets and Global Sustainability, firstly without a carbon constraint to give a baseline, then imposing additional change to reach targets of 45%, 60% and 70% reductions. Figures from this study have been factored up by 15% to give end user emissions.

All five studies assume that some fuel switching will occur in transport. This is at its most extreme in the AEA Technology/ICCEPT study where the remit was to explore technological solutions. In this case up to 98.6% of transport power is from hydrogen fuel cells.

Efficiency measures suggested include increasing the fuel efficiency of current vehicles, the use of hybrids, and the reduction of road congestion to help reduce emissions produced by stop start movements, although IAG also see congestion as a constraint on traffic growth.

All the studies (except AEA Technology/ICCEPT, which had a specific brief) recognize the need for some behavioural change. The Carbon Trust Study incorporates some changes into Baseline 2 in the form of modal switching and no new roads. IAG suggestions included no new road build beyond 2010, and reductions in rail fares to encourage modal switch. However, the detail on how these measures would be achieved was not clear.

None of the studies included emissions contributions from the growing international aviation sector. At present Kyoto targets only include emissions from the domestic sector. However it is recognised that if international emissions were shared out, the UK would find it considerably more difficult to reach a 60% reduction target (IAG, 2002).

The PIU (2002) suggest that there will be increased demand for road transport which will remain dependent on oil for the next two decades, though this is likely to be offset by increased energy efficiency in road transport. This was considered to provide "a synergy with security objectives (no increased dependence on oil)" and "environmental objectives (no increase in greenhouse gas emissions; reduced vehicle noise)". The PIU also indicated that energy efficiency measures could increase the price of new vehicles. There was little information in the other studies on possible conflicts and competition between or within sectors or how these might be resolved or avoided.

It is clear from these studies that emission reductions from the transport sector are expected to arise from technological measures. This raises two issues for concern. Firstly, recent improvements in efficiency have been offset by a range of factors including: increased mileage driven by economic growth and lower motoring costs, increased size and weight of vehicles, and wider uptake of additional features such as air conditioning (Bristow, 1996, Fergusson, 2001, IPCC, 2001b). Secondly there is the possibility that the technology may not develop as quickly or as cost effectively as anticipated. This issue is recognised by the RAC Foundation (2002) which suggests that other options, which constrain the demand for vehicle use, need also to be examined.

### 2.4 Transport Scenarios and Targets

In this section specific scenarios for the transport sector are developed drawing on the studies reviewed. Two carbon dioxide emissions targets for the UK are examined and the role of the transport sector in achieving these targets is considered.

The carbon dioxide emission targets are determined using the RCEP interpretation of the contraction and convergence approach outlined above. The focus here is on the transport reductions needed to achieve the 450 ppm and the 550 ppm stabilisation targets.

A 450 ppm stabilisation target requires a 79% reduction in carbon dioxide emissions from 1997 levels by 2050. Since carbon dioxide emissions were 148 MtC in 1997 in the UK (DEFRA, 2002), stabilisation at 450 ppm means UK carbon dioxide emissions would need to fall to 31.1 MtC per annum in 2050. A 550 ppm stabilisation target requires a 58% reduction in carbon dioxide emissions from 1997 levels by 2050. To achieve stabilisation at 550 ppm, UK emissions would have to fall to 62.2 MtC per annum in 2050.

The key question is what role should transport play in achieving the overall carbon dioxide reduction targets identified as necessary to achieve stabilisation. Clearly there is considerable uncertainty about how much of a contribution to overall emissions will be made by different sectors. Two different options have been developed based on the forecasts discussed earlier. Option 1 assumes that transport's emissions remain at the same proportion of total emissions as in 1997. Option 2 allows transport's proportion of total carbon dioxide emissions levels to increase in line with forecasts.

**Option 1: Transport's contribution fixed at 1997 levels**
In 1997 the end use of transport produced 39 MtC of the total 148 MtC from carbon dioxide emissions, a 26.4 % contribution. Applying the 26.4% to the 31.1 and the 62.2 MtC overall emissions targets results in transport contributing 8.2 MtC and 16.4 MtC.

**Option 2: Transports contribution derived from forecasts**
The second approach looks at the implications of existing forecasts for transport emissions. To determine the potential future contribution from transport, four of the five studies previously analysed were used. The RCEP work was not included, since the role of transport in achieving stabilisation of demand at 1998 levels is not quantified. Table 2 shows as the transport baseline for each study what might happen in a non-carbon constrained world. There is a range but for those scenarios that are closest to business as usual the figure is around 40%. Although the PIU do not use a baseline, their forecasts for World Markets suggest that transport's share could be as high as 54%. In a carbon

constrained world there is a wide range of predictions for transport's contribution. When compared to their non-carbon constrained forecast, the Carbon Trust and the IAG suggest that transport's share of emissions could be even higher; the PIU figures roughly correspond with those for a non-carbon constrained world; while the AEA Technology/ICCEPT work suggests a lower contribution.

To determine transport's future contribution it was decided to use the average contribution from transport to emissions in a carbon constrained world. This results in a higher contribution from the transport sector of 41.4%. This is in line with other UK research (DTI, 2003b) which indicates that transport carbon savings are among the higher cost options, compared to other sectors, and hence it is to be expected that transport's percentage carbon contribution may end up higher than it is now. The 41.4% figure is also close to the estimates for a non-carbon constrained world. Applying this to the 31.1 MtC and the 62.2 MtC results in emissions of 12.8 MtC and 25.7 MtC. Table 2.3 shows the derived emissions targets for the transport sector.

**Table 2.3: Transport target emissions**

| | To achieve 450ppm stabilisation | To achieve 550ppm stabilisation |
|---|---|---|
| Total Emissions in 2050 | 31.1 MtC | 62.2 MtC |
| Transport target emissions in 2050 | | |
| Option 1 (26.35% contribution) | 8.2 MtC | 16.4 MtC |
| Option 2 (41.27% contribution) | 12.8 MtC | 25.7 MtC |
| Reduction from Transport's 1997 emissions (39 MtC) | | |
| Option 1 (26.35% contribution) | 30.8 MtC | 22.6 MtC |
| Option 2 (41.27% contribution) | 26.2 MtC | 13.3 MtC |

Option 2 is based on forecasts and is therefore probably the better representation of the role of transport. However, the more stringent targets in Option 1 are also useful, given the risk that other sectors may not be able to deliver reductions in excess of the 60 and 80% targets to 2050. Emissions from international air travel alone (excluded from these estimates) are forecast to exceed all but the weakest target by 2030. Whatever is achieved domestically will need to be matched by action on international aviation.

## 2.5 Conclusions

The objective of this phase of the work was to establish $CO_2$ emission targets for the UK transport sector in 2050. A literature review suggested two stabilisation targets for $CO_2$ of 550 ppm and 450 ppm. For the UK this implies total emissions in 2050 of 62.2 and 31.1 MtC respectively. Work then moved on to a review of five key studies containing future scenarios for $CO_2$ emissions for the UK. These studies were used firstly to establish feasible 2050 baseline projections for the UK and secondly to examine possible ways in which reductions could be achieved.

Two approaches were used to estimate the contribution of transport to total emissions in 2050:

- stabilisation at the current level of approximately 26%
- an increase to approximately 41% derived from the studies reviewed

These percentage contributions were then applied to the 62.2 and 31.1 MtC emission targets and the emission reductions needed from transport's 1997 levels calculated. The results gave a range of targets from 8.2 MtC to 25.7 MtC and a range of reductions from 13.3 MtC to 30.8 MtC. Even the weakest of these targets implies a significant reduction from current emission levels. When set against the forecast growth in emissions shown in Table 2.1, the weakest target would require a 50% reduction from trend by 2020.

## 3. DEVELOPING STRATEGIES TO MEET THE TARGETS FOR LAND BASED PASSENGER TRANSPORT[e]

Overall targets for reducing $CO_2$ emissions were derived in Chapter 2. The second step was to establish the contribution of personal land based transport to this total, which is currently around 65%. Analysis of the National Road Traffic Forecasts (DETR, 1997) suggests that personal land based transport's contribution to transport emissions is likely to fall to around 60% in 2050. The estimated targets for transport as a whole and for personal land based transport, assuming a 60% share of transport emissions, are shown in Table 3.1.

While these are targets for 2050 the earlier they are achieved the better in terms of mitigating the impacts of climate change.

**Table 3.1 Target emissions from land based personal transport for the UK in 2050**

| | 41.27% contribution | 26.35% contribution |
|---|---|---|
| 79% reduction (31.1 MtC) | | |
| Total transport<br>Personal land based transport | 12.8 MtC<br>7.7 MtC | 8.2 MtC<br>4.9 MtC |
| 58% reduction (62.2 MtC) | | |
| Total transport<br>Personal land based transport | 25.7 MtC<br>15.4 MtC | 16.4 MtC<br>9.8 MtC |

To place these emission targets into context, potential carbon emissions in 2050, from the land based personal transport sector, were calculated. The initial assumption is that no improvements in car vehicle technology or changes in policy take place, giving what could be termed a worst case trend forecast. Current well to wheel emissions per kilometre were combined with predicted increases in car vehicle kilometres. Low, Central and High National Road Traffic Forecast (NRTF) (DETR, 1997) estimates were used with a continuation of trend assumed for the period 2031-2050. Current car vehicle kilometres are approximately 380 billion. The forecasts to 2050 give a range from 494 billion kilometres under the low growth assumptions to 686 billion kilometres under a high growth assumption. This results in carbon emissions from cars increasing from approximately 21.5 MtC to 33.8 MtC under the central NRTF assumptions.

Assumptions are also required on the levels of emissions from bus, rail, motorcycle and the manufacture of vehicles. It was assumed that increases in efficiency would reduce carbon emissions from these sources from approximately 5.5 MtC at present to 1.6 MtC in 2050. Although this is a strong assumption it was thought plausible due to increased electrification of rail and because it is easier to introduce new fuels and technologies in fleet based vehicles (buses).

The total carbon emissions from personal land based transport under our trend scenario for NRTF central growth assumptions are shown in Table 3.2.

**Table 3.2 Trend growth in total Carbon emissions from personal land based transport under central growth forecasts (MtC)**

| | 2001 | 2010 | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|---|---|
| Emissions | 27.0 | 30.2 | 31.6 | 32.9 | 34.2 | 35.4 |

[e] This chapter is based on a paper given to the European Transport Conference, Pridmore et al 2003

## 3.2 Developing Strategies to Meet the Targets

In order to examine how the targets in Table 3.1 might be achieved it was essential to gain a clear idea from the literature of the possible contribution of individual categories of measures, namely, technology, public transport, walking and cycling, restraint measures and land use. Most estimates in the literature on impacts are short or medium term, given the uncertainties associated with long run forecasts. We have developed a strategy for implementation for each measure, based on the best evidence from the literature and taking into account some constraints on acceptability. When looking at technology we have tried to identify two possible paths, but not the policies that would be necessary to secure such change. When considering other policy areas we have considered evidence on existing relationships to prices, service quality etc and attempted to identify the strategies that could be implemented and the changes in traffic levels that could be secured. We have to some extent taken practical feasibility, acceptability and phasing of measures into account. Improvements to public transport occur only after 2015 given the current condition of the rail network, road user charging is initially revenue neutral and in this case improvements to public transport occur only after revenue is generated which might contribute to them. Note that these scenarios are intended to be exploratory and illustrative of what might be achieved and they may be subject to further change. We recognise that many different approaches could have been taken and we present here only a subset of the possibilities. At the end of this section we consider the extent to which effects could be additive.

### 3.2.1 Technology

The role of technology and changes in purchasing behaviour to favour low emission vehicles was considered first, as this will form the base for further policy intervention.

It is expected that technological developments will play a major role in achieving emissions reduction, including: hybrid vehicles, fuel cell vehicles powered by hydrogen, and more efficient petrol vehicles. Average well to wheel emissions per vehicle kilometre for the current car fleet are 205.5 grams $CO_2$.

To consider the potential impact of the use of lower carbon vehicles, two scenarios A and B were developed. Both scenarios assume full implementation of the ACEA/EC (1998) agreement to achieve average new vehicle emissions of 140g $CO_2$/km by 2008. Scenario A assumes no further significant change and gradual fleet turnover to give a 25% reduction in emissions by 2050. Scenario B assumes a combination of new technology, improvements to current technology and changes in purchasing behaviour toward more efficient vehicles to yield a 60% reduction in emissions by 2050. The estimated well to wheel carbon dioxide emissions per vehicle kilometre are shown in Table 3.3.

**Table 3.3 Well-to-wheel Carbon Dioxide Emissions g/km**

| | 2001 | 2010 | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|---|---|
| Scenario A | 205.5 | 176.4 | 171 | 165 | 160 | 154 |
| Scenario B | 205.5 | 176.4 | 146 | 120 | 100 | 82 |

The best performing vehicles in terms of well to wheel $CO_2$ (tailpipe emissions are uplifted by 1.15 to provide a well to wheel figure) emissions available in the UK are : Honda Insight petrol/electric hybrid 1.0 IMA coupe (92), Renault Clio 1.5 80bhp diesel (126.5), the Smart City Coupe Pure petrol (130) and the Toyota Prius 1.5 petrol/electric hybrid (131.1) and a number of smaller diesel cars are approaching this level. We therefore have a scenario (A) that is achievable using existing technology and one (B) that requires substantial technological advance, investment and widespread adoption of new technology.

Figure 3.1 maps the trend scenario as outlined in section 3 alongside A and B. For each scenario in this and future graphs the low, central and high NRTF estimates are illustrated. Under scenario B the weakest target is met for the low and central growth forecasts.

Further technological gains may be possible, based on a switch to hydrogen propulsion by 2050 but considerable uncertainties remain with regard to the eventual development of the technology, the availability of carbon neutral hydrogen and the pace of change. It is unlikely that all the hydrogen required could be sourced from the carbon neutral sources necessary to secure reductions in emissions. Thus far hydrogen powered vehicles do not offer considerable overall savings in $CO_2$ largely due to the ways in which hydrogen is produced and stored (Pridmore and Bristow 2002). The initial potential savings from hydrogen are higher in sectors other than transport.

We view a 60% reduction in $CO_2$ emissions from technology as a fairly optimistic scenario. It is clear that behavioural change will be needed as an essential part of any strategy to achieve a low carbon transport future. Such behavioural change could also facilitate early movement in the direction of the targets, which is crucially important in order to prevent the build up of greenhouse gases in the atmosphere.

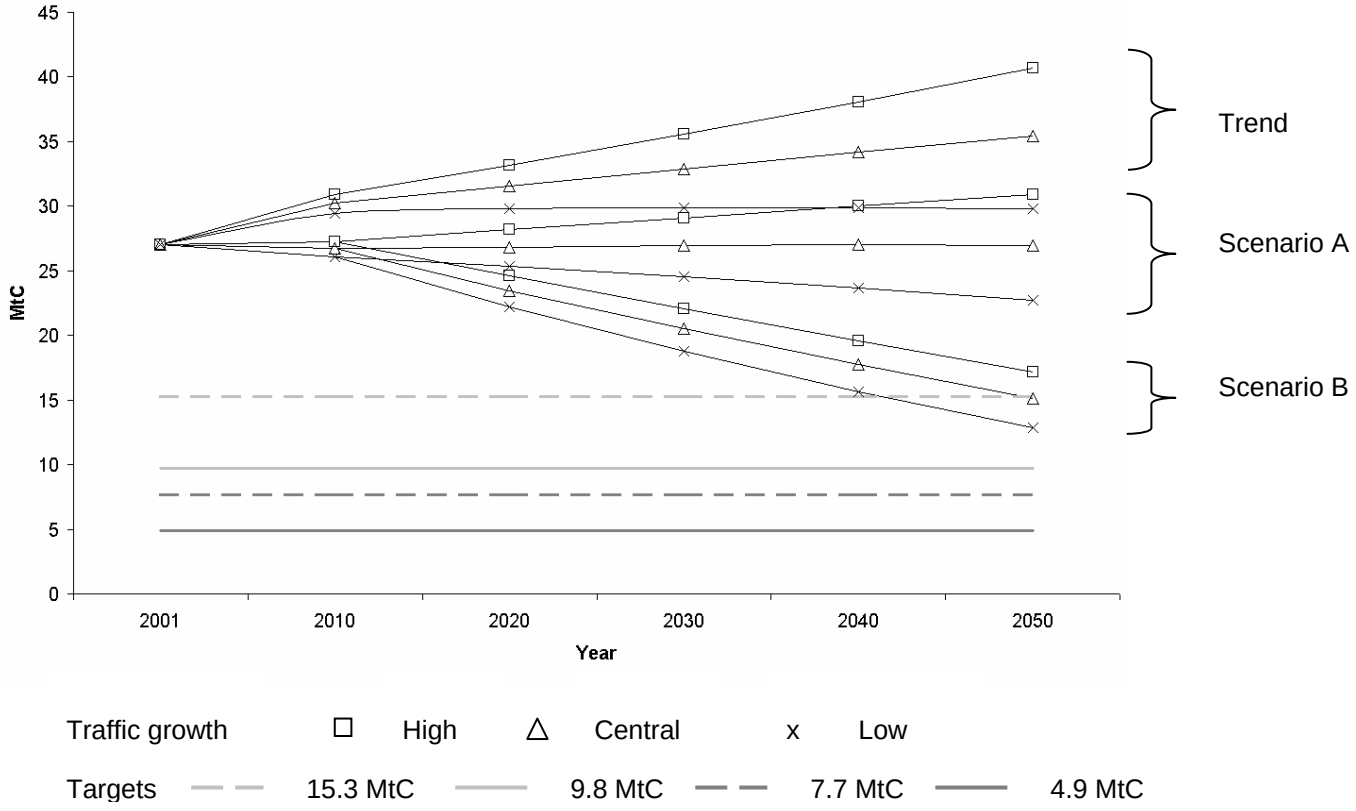



**Figure 3.1 $CO_2$ Emissions Under the Trend, A and B Scenarios**

### 3.2.2 Pricing for Road Use

Two possible measures were considered (i) a national road user charge per vehicle kilometre and (ii) increases in fuel taxation. Increases in fuel taxation would not only reduce car use but also give an added incentive to chose a more efficient or alternatively fuelled vehicle. However, road user charging has advantages in that it may be varied according to when and where the mileage occurs and hence can be used to address other objectives of transport policy relating to efficiency and environmental impacts and may also prove to be more acceptable. We therefore considered both and attempted to identify a feasible pathway.

It is assumed that national road user charging is implemented in 2010 and is revenue neutral to 2015, offset by reductions in vehicle excise duty and fuel duty and yields a maximum 5% reduction in

vehicle kilometres (CfIT, 2002). Between 2015 and 2020 the charge increases by 2% per annum. For this time period a short run elasticity of -0.16 is used (Brown et al, 1993). Between 2020 and 2030 it is assumed that the charge increases by 4% per annum, and a long run elasticity of -0.31 is used (Brown et al, 1993). Figure 3.2 shows the carbon emissions produced when road user charging is combined with scenarios A and B under the three different levels of NRTF traffic growth. At this stage the impact on public transport of modal shift is not considered - effectively trips are either suppressed or switched to existing public transport services or non-motorised modes.

Fuel consumption is more sensitive to price than traffic levels. Graham and Glaister (2002) estimate the price elasticity for fuel consumption to be –0.2 to –0.3 in the short run and –0.6 to –0.8 in the long run while for traffic levels the elasticities are –0.15 and –0.3 respectively. In this analysis we examine the change in traffic levels, as we have already made some assumptions relating to technology, albeit without policy incentives to secure such changes. The impacts from a similar implementation and pricing strategy as for national road user charging would lead to a similar reduction in traffic levels.

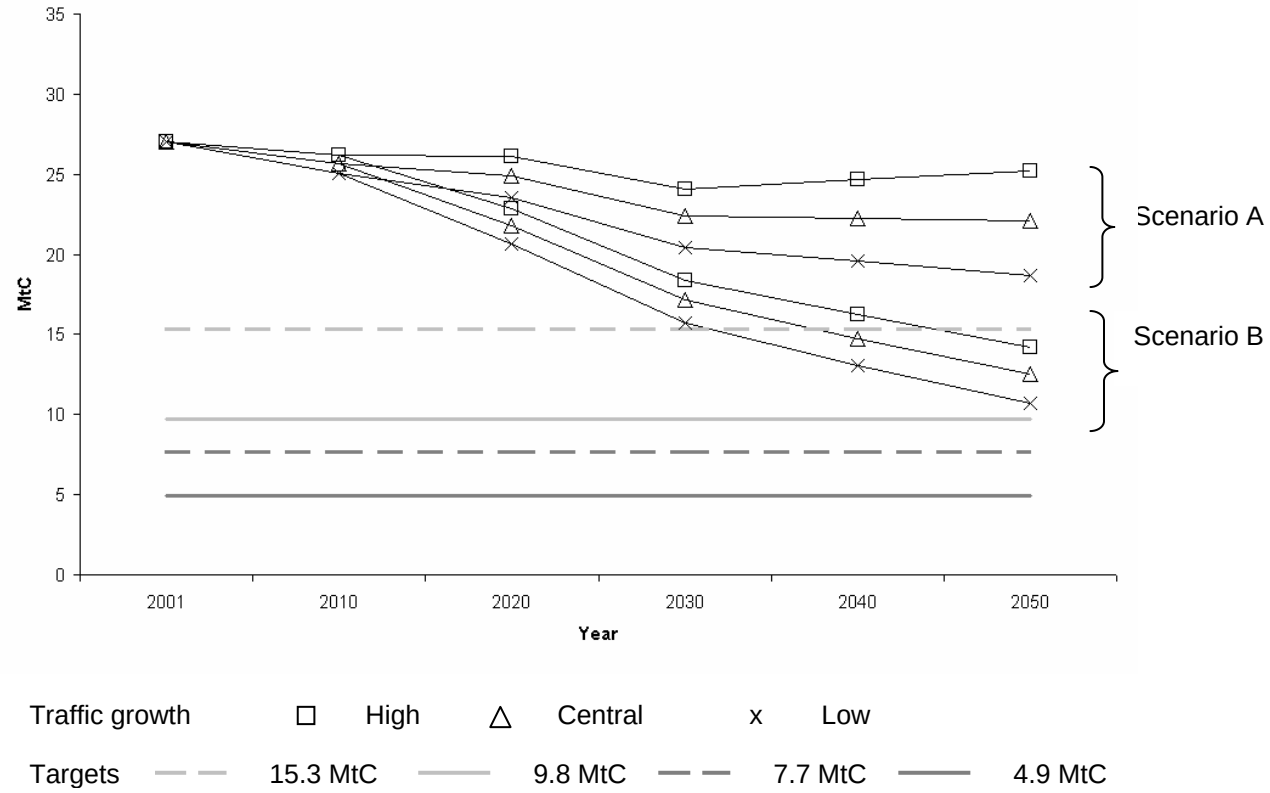



**Figure 3.2 $CO_2$ Emissions Under Scenarios A and B with Road User Charging**

As Figure 3.2 shows, the addition of a strong price signal in combination with the substantial technical advance of Scenario B reaches the weakest target under all the NRTF assumptions. To reach the target of 7.7 MtC under Scenario B, prices would have to rise by 7.3% a year from 2015 to 2050 (under central traffic growth). Scenario A is still not close to the weakest target. In order to reach the strongest target under Scenario A prices would have to rise by 19% a year from 2015 to 2050, reducing vehicle kilometres to 75 billion.

### 3.2.3 Public Transport

Our key interest is in the diversion of trips from car to public transport. To derive car cross elasticities the method set out in Dodgson (1991) and Acutt and Dodgson (1996) is used and the resulting elasticities are shown in Table 3.4.

**Table 3.4 Key assumptions used to derive car cross elasticities**

| | Own price elasticities | Relative mode shares[3] | Diversion factors | Conversion factor for % changes in car passenger miles | Resulting car cross elasticity |
|---|---|---|---|---|---|
| Bus short run | - 0.40[1] | 9.05% | 17%[4] | 0.32 | 0.0020 |
| Bus long run | - 0.90[1] | 9.05% | 17%[4] | 0.32 | 0.0044 |
| Rail short run | - 0.65[2] | 9.9% | 36%[5] | 0.87 | 0.0202 |
| Rail long run | - 1.08[2] | 9.9% | 36%[5] | 0.87 | 0.0335 |

Sources: [1]Dargay and Hanly 2002, [2]Goodwin 1992, [3]Bristow et al 2002, [4]Nash 2002, [5]derived from Acutt and Dodgson 1996 22% and Vicario 1999 50%.

Bus fares are assumed to fall by 3% per annum and service levels increase by 5% per annum between 2015 and 2035. Rail fares fall by 5% and service levels increase by 3% per annum between 2015 and 2035. After 2035 fares are held constant.

Decreasing fares and improvements in service provision are not the only ways of increasing the attractiveness of public transport; additional methods include improvements to interchange, simplification of fare structures, increased information provision, better integration between modes, adherence to timetables (reliability), and for bus increased priority. It is difficult to quantify the impact of these improvements. However, TAS (2001) suggest that reliability could be almost as influential as service level and also illustrate the potential return from quality packages. Here such measures are assumed to be half that of the fare and service impact combined. This might be viewed as a favourable assumption.

The 2030 emission reductions for public transport are partly offset by the provision of additional services. It is assumed by 2050 that the use of much lower emission buses and electrified trains powered by renewable energy remove this impact.

The analysis suggests that improvements to public transport could lead to a 8% reduction in vehicle kilometres driven in 2050. Rail provides 7% and bus 1% of this.

Depending on the scenario and growth rate the additional reduction offered by improvements to public transport would be between 0.89 and 2.34 MtC by 2050. The weakest target is met by 2050 only under Scenario B with low and central NRTF growth. Compared with technology alone no new targets are met.

### 3.2.4 Telecommunications

Our assumptions for 2050 are based on Salomon (1985) Van Ommeren et al (in Lake, 1997) and Handy and Moktarian (1996) such that by 2050 telecommunications replaces: 40% of business travel, 16% of commuting trips (assuming 40% of the commuters telework for two days every week) and 40% of shopping trips. The impacts on both car and public transport were calculated, and it was assumed that this replacement of travel would occur gradually. The outcome may be viewed as optimistic as we have assumed that all the car mileage is saved, whereas the car may be used by others in the household or the telecommuter may use it for additional trips (Hopkinson et al 2002).

Depending on the scenario and the traffic growth used the additional emission reductions offered in 2050 vary between 1.95 MtC and 5.06 MtC. The weakest target is met by 2050 only under Scenario B for low, central and high NRTF growth.

### 3.2.5 Land Use Measures and Improvements to Walking and Cycling Facilities

Land use measures include: increasing development densities, the use of maximum parking standards and altering development patterns to encourage provision and use of public transport, and walking/cycling facilities (May and Matthews, 2001). To achieve significant traffic reduction, alterations to land use need to be integrated with transport policies (Paulley and Pedler, 2000). The DOE/DOT (1993) suggest that land use planning policies in combination with transport measures could reduce transport emissions by 16% over a 20-year period while more recently WS Atkins (1999) suggest reductions in traffic of up to 2% could be achieved by 2010. For our scenario we have assumed that by 2050 land use measures alone could lead to traffic reductions of 10%.

Depending on the scenario and NRTF rate used, reductions of between 1.60 and 4.20 MtC could be achieved in 2050. The weakest target is met by 2050 only under Scenario B for low, central and high NRTF growth.

### 3.2.6 Combinations of Measures

Thus far even under scenario B no measure has achieved anything but the weakest carbon reduction target. Table 3.5 summarises the individual measures examined.

**Table 3.5 Emission Levels under Scenarios A and B for central NRTF forecasts (MtC)**

| Intervention | 2030 | | 2050 | |
|---|---|---|---|---|
| Trend | 32.9 | | 35.4 | |
| | Scenario A | Scenario B | Scenario A | Scenario B |
| Lower Emission Cars (LEC) | 27.0 | 20.5 | 27.0 | 15.3 |
| LEC + Road Pricing | 22.4 | 17.2 | 22.1 | 12.5 |
| LEC + Fuel Prices* | 22.5 | 17.3 | 22.2 | 12.6 |
| LEC + Public Transport | 26.3 | 20.3 | 24.9 | 14.0 |
| LEC + Telecommunications | 24.3 | 18.5 | 22.4 | 12.6 |
| LEC + Land Use | 25.0 | 19.0 | 23.3 | 13.2 |

* Impact on traffic levels

In looking at combinations so far technology in combination with pricing appears to deliver the greatest reduction by 2050. If applied using fuel prices, this would also incentivise drivers to move to efficient vehicles and to adopt new technology earlier. The next question is the degree to which each measure secures benefits additional to the others. We have distinguished in Table 3.6 between four levels of interaction between measures:-

- \- substitutability: measure A has a similar impact to measure B, and can replace, but not add to it;
- \+ complementarity: the combined effect of measures A and B is greater than either alone but less than their sum;
- ++ additivity: the combined effect of measures A and B is equal to the sum of their individual effects
- +++ synergy: the combined effect of measures A and B is greater than the sum of their individual effects.

**Table 3.6 Expected Interactions Between Measures**

| | Road Pricing | Fuel Pricing | Public Transport | Telecommunications | Land use | Technology |
|---|---|---|---|---|---|---|
| Road Pricing | | | | | | |
| Fuel Prices | - | | | | | |
| Public Transport | + | + | | | | |
| Telecommunications | + | + | ? | | | |
| Land use | + | + | + | ? | | |
| Technology | ++ | +++ | ++ | ++ | ++ | |

It is clear that there is positive interaction between road and fuel pricing and the additional measures. It is likely that some changes such as increased use of telecommunications will occur independently of transport policy. It does seem justified to add the impacts of technology to those of fuel or road pricing as our estimates considered the effect of pricing on road traffic rather than on efficiency gains. However, if pricing is implemented then this will increase uptake of public transport and this will reduce the impact of price and service changes on public transport, as there are now fewer car users to switch. Similarly pricing is likely to drive the take up of telecommunications and the development and use of walkable communities.

### 3.3 Interviews with Experts

Face to face interviews were carried out with 7 experts with transport policy and technology backgrounds. As part of the interview design process and as an informative exercise in its own right, a brain storming session was held in ITS in January 2003. The interviews took place over a three-week period (March-April 2003) and in the majority of cases were at the workplace of the interviewee. Prior to the interview the background information note was emailed and a colour copy posted to the interviewee. The background information note summarised our carbon reduction targets and provided detailed information about the role of technological and behavioural change in reducing transports carbon emissions. Topics for discussion at the interview were also suggested.

Overall the interviews went well. The background paper and suggestions for discussion topics helped provide a framework to the interview. Key results from the discussions are detailed below. Where appropriate reference is made to the ITS brainstorming session.

For technology it was clear that large reductions in carbon emissions are expected by 2050. Incremental improvements and modifications to internal combustion engines were likely to occur first. Hybrid vehicles were seen as playing a significant role in achieving carbon reduction. One respondent thought that the higher cost of hybrid technology would remain a barrier.

Increasing dieselisation of vehicles would also offer carbon reduction benefits. With diesel hybrids offering a 40% reduction compared to current conventional petrol vehicles. However diesel vehicles emit higher levels of small particulates and $NO_X$ and there is therefore a potential conflict between air quality and climate change objectives.

In the longer term hydrogen fuel cell vehicles were seen as a possibility. However there were reservations, especially concerning the production of hydrogen and its storage (note the objections from residents of Havering to the siting of a BP hydrogen refuelling station nearby (Macalister, 2003)). It was apparent that the experts were less ‘sure’ about a hydrogen transport future than reports in the press and recent government literature would suggest. Other fuel sources, for example biofuels, were suggested.

To achieve an increase in fuel efficiency, changes had to be implemented at the European level, therefore future ACEA/EC agreements were seen as an important strategy. This was also a conclusion of the ITS brainstorming session. Other suggestions included grants to partially offset the additional cost of lower carbon vehicles as currently offered by Powershift for the purchase of hybrid vehicles. Changes in the tax system to favour the purchase of more fuel-efficient vehicles were also put forward. Those with a transport policy background were more in favour of fuel pricing as a mechanism to encourage the use of lower emission vehicles than people who were more technology orientated.

For behavioural change there was an emphasis on road traffic restraint measures. It was suggested that the government's recent recognition that congestion reduction targets would not be met by the Ten Year plan coupled with a growing realisation that the extent of road build required to meet anticipated traffic growth would not be acceptable, would ensure that traffic restraint measures would be implemented in the longer term. The introduction of road user charging for Heavy Goods Vehicles in 2005, and the initial success of the London congestion charging scheme were also seen as contributing to a move to wider restraint measures. There was an emphasis on road pricing though road space re-allocation and fuel prices were also considered as restraint measures. The concept of fuel/carbon permits was not mentioned though was suggested in the brainstorming session. Initially a package of different traffic restraint measures would need to be implemented. Two of the technology experts thought the impact of traffic restraint low in proportion to the cost to the individual. The impact of restraint measures could be higher than our modelling suggests because of lifestyle changes in the longer term. In terms of public acceptance to the scheme it was thought that the initial implementation would be the hardest part.

It was recognised that there would be synergy between measures and that if the 'stick' of traffic reduction measures were implemented then 'carrots' would also be needed. There was agreement that improvements to public transport worked well with traffic restraint measures and that if pricing was involved this would act as a source of potential funding. There was also the suggestion that if road restraint measures were introduced then rail might then have the edge in competitive terms and the private funding for the railways assumed in the Ten Year Plan might become more readily available. Several public transport issues were raised. These included the location of new rail stations and services since new stations may simply encourage people to locate at greater distances from their workplace. Another issue was the ability of the public transport system to cope with the modal shift however it was noted that the system had accommodated change in the past. The impact of lifestyle change in the longer term was also considered and a move to a multi-modal lifestyle was thought possible.

Increased use of telecommunications was expected regardless of transport issues. The benefits in terms of carbon reduction were queried as additional energy could be used to travel in the time now freed from commuting and to heat and light the home during working hours. It was suggested that steps should be taken to ensure that the most energy efficient telecommunications technologies were used.

For land use our assumptions were thought to be reasonable. The general assumption that land use change takes place over the longer term and transport infrastructure change over the shorter term, was questioned by one respondent, suggesting that structural regeneration of UK cities could be quicker than implementing a light rail scheme.

The impact in carbon emission reductions was not quantified by any of the experts. The impacts and synergy would depend very much on individual circumstances. One expert said it would be impossible to quantify at a national level and extremely difficult at a local level. A matrix table indicating positive and negative synergy was thought an appropriate solution.

Experts also suggested several areas of policy, which we had either not considered or which needed further attention, these included: the impact of telematics, the impact of more fuel efficient driving

practices including further speed restrictions on the motorway, the replacement of short car trips by walking and cycling, the consideration of soft factors (in particular travel plans and individualised marketing), changes to taxation and the potential for increased competition between UK domestic flights and rail.

It is thought possible that real time driver information could produce a 6% reduction in mileage driven (Graham and Marvin, 1999). While more fuel-efficient driving practices for example: keeping tyres inflated at the correct pressure, avoiding excessive acceleration and observing motorway speed limits could result in a 5-20% improvement in fuel efficiency (Potter et al, 2001). The introduction of further speed restrictions on the motorway would bring about significant reductions in vehicle emissions since vehicle emissions are at their lowest at around 50mph rising on average between 30% and 35% between 70mph and 80mph (DETR, 2000). However such limits are unlikely to be publicly or politically acceptable at present.

Approximately 17% of all car distance travelled as a driver is for journeys of less than five miles (analysis using Potter, 1997). If 20% of these trips were replaced by walking or cycling and taking into account the 40% extra carbon production that results from the inefficiency of driving short distances, there could be a fall of approximately a 4.8% in carbon emissions from car use. A 20% replacement may be overoptimistic at the present time. Work by Mackett (2000) found that actions to encourage transfer from cars to walking and cycling could reduce the distance travelled by car by about 0.3% for walking and 0.4% for cycling, allowing for the inefficiency in driving short distances this would only result in around a 1% reduction in carbon emissions.

A review of 20 UK case studies on the impact of travel plans found that on average there was an 18% reduction in the proportion of commuter journeys being made as a car driver (DfT, 2002b). Quantitative results from travel blending programmes indicate that a 10% reduction in car driver kilometres is possible though further research is needed before results can be generalised (Rose and Ampt, 2001). In terms of overall impact Halcrow (2002) suggest workplace travel plans could lead to a 0.6% reduction in vehicle kilometres while Eco-Logica (2002) suggests a 2.4% reduction due to workplace travel plans and 1.3% reduction due to school travel plans.

Changes to taxation included alterations to the personal taxation regime to encourage modal shift, and these are already being considered by the DFT (2001). It was found that tax changes could help ease the development and benefits of company travel plans. More radical changes included the use of ecological taxation, here consumption would be taxed rather than labour.

In terms of carbon emissions a move to an increase in domestic aviation at the expense of rail transport would lead to large increases in carbon and other greenhouse gas emissions at approximately five times higher than those for rail.

### 3.4 Packages of Measures to Meet Targets

In this section we focus on one target to allow us to elaborate in some detail three strategies that could meet a target of 12.6 MtC by 2050, which is the midpoint between the 15.4 and 9.8 target detailed in Table 3.1. A 12.6 MtC target relates to a 58% reduction in carbon emissions by 2050 and a stabilisation target of 550 ppm. This reflects the target in the Energy White Paper (DTI, 2003). In order to achieve stabilisation at 450 ppm more dramatic strategies would have to be envisaged. The strategies are based on our modelling work and the interviews with experts.

Strategy 1 involves dramatic technological change affecting both the type of fuel and power mechanism used. There is no behavioural shift and car vehicle kilometres grow in line with central NRTF forecasts from 380 billion to around 600 billion. To reach the 12.6 MtC target carbon emissions per vehicle kilometre would have to fall to 66 grams of carbon dioxide per kilometre. A car fleet that was 42% hybrids and 58% powered by carbon neutral hydrogen fuel cells might achieve this. Hydrogen could be provided by electrolysis in which case a 39% increase in current electricity

production would be required. If produced from woody biomass then approximately 36% of UK arable land would have to be used to produce the crop.

Strategy 2 involves a mixture of both technological change and measures to ensure reduction in demand. The average vehicle would emit 88.4 grams of carbon dioxide per vehicle kilometre. A car fleet that was 68% hybrids and 32% powered by hydrogen fuel cells could achieve this. Under this scenario car vehicle kilometres grow from 384 to approximately 450 billion. This level is considerably below the central NRTF and will therefore require measures to reduce car use. Options include increasing the price of fuel by 2% a year from 2015 to 2050, an increase of 100% by 2050, or a nationwide road user charging scheme, revenue neutral from 2010 to 2015 and then increasing by 2% a year to 2050. The pricing measure would need to be accompanied by other measures to induce modal shift through bus and rail fares decreasing at 1% per annum and increased service provision at 1% per annum over the period 2015-2035. Additional methods of encouraging modal shift would include improvements to interchange, increased information provision, adherence to timetables and, for bus, increased priority.

Strategy 3 involves less technological change. Carbon dioxide emissions per car vehicle kilometre would be 133.6 grams per kilometre. This is achieved through improvement in fuel efficiency of internal combustion engines and use of hybrids. However, car vehicle kilometres would need to fall from current levels of 384 billion to 300 billion. To achieve this change options include increasing the price of fuel by 5.5% per annum from 2015 to 2050, an increase of 550% by 2050 or road user charging revenue neutral 2010 to 2015 and then increasing at 5.5% a year. Improvements in public transport on a similar scale to Strategy 2 would also be necessary. People would also be encouraged to live nearer their place of work, and telecommute. Walk and cycle facilities would be improved and there would be increased provision of local shops and facilities. The very large price increases under this strategy might well be expected to generate further gains in vehicle efficiency. Significant changes to attitudes and lifestyles would need to occur.

Strategy 1 offers a technological solution, assuming the technology delivers and that massive increases in electricity generation are feasible or a vast switch in arable crops. The main technological changes are likely to come towards the end of the time period, and it is therefore a risky scenario. Strategy 2 provides a mix of measures including an average vehicle performance beyond the best on the market to date. In order to restrain traffic growth the policies might be seen as fairly draconian, but this is in part due to the proposed delays in their implementation to reflect political acceptability. Strategy 3 is difficult to envisage without a large shift in attitudes, behaviour, lifestyles and the world around us.

### 3.5 Conclusions

We are operating in an area of great uncertainty as to what the transport system could look like in 50 years' time. However, we have endeavoured to establish possible routes towards a low carbon future for personal land based transport. Key findings are:

1. Technology cannot be the sole measure for reducing $CO_2$ emissions:
    - there is uncertainty as to the level of reduction that can be delivered in terms of vehicle technology and securing carbon neutral sources of hydrogen;
    - any cuts will be offset to some extent by increased demands; and
    - it is important that reductions are secured sooner rather than later if key stabilisation targets are to be achieved.

2. Clear price signals to car users appear to be the most effective measure alongside technological change. The use of the price of conventional fuel as the instrument will also give an additional incentive to travellers to switch to more efficient vehicles or to adopt new technologies earlier than would otherwise be the case.

3. Improvements to passenger transport, cycling and walking facilities, the siting of facilities closer to home and the increased use of telecommunications will also be required if change is to occur on a sufficient scale.

4. Existing knowledge is stronger on technology and pricing effects than on measures relating to telecommunications, service quality, walking, cycling and land use. However, even for these, we cannot be certain that current elasticities will apply in fifty years time. There is uncertainty as to the nature of long run adaptation and life style change.

5. Our scenarios have been constrained by political and social acceptability, hence the relatively late introduction of both pricing and improvements to public transport. However, if these measures were introduced earlier, the required increases to say petrol prices would be less extreme as the traffic growth in the years prior to the 2010 and 2015 implementation dates could be avoided.

Thus far we have derived targets for $CO_2$ reduction in the land based passenger transport sector and using best estimates from the literature derived possible ways of reaching these. The next step reported in chapter 4 was to obtain further expert opinion on both the targets and the strategies.

## 4. EXPERT CONSULTATION

### 4.1 Introduction

A Delphi survey of experts was conducted to investigate how deep cuts in carbon dioxide emissions from the personal land-based transport sector could be made. A range of low carbon strategies were developed in chapter 3 based on trends, evidence on technological development and the academic literature on behavioural response. The Delphi survey aimed to explore the importance of a range of technological and behavioural measures in reducing carbon emissions from personal land based transport and to test further the feasibility, desirability and likelihood of the scenarios.

### 4.2 The Survey Process

The survey process was designed to generate over a short period (September to November 2003) a set of opinions about how carbon dioxide emissions are likely to change from present levels by 2050. The personal land-based transport sector was considered in detail with levels of projected traffic growth and emissions targets being examined. The people we consulted were either involved in transport-related research, or part of transport policy or industrial communities and were mainly based in the UK. The survey was conducted in two stages:

1. A paper-based survey using a detailed questionnaire ran for three weeks, ending in late September 2003. The aim was to generate as much data as possible without making it onerous for the participants. 77 people were identified as having knowledge of this field and were invited to participate. 16 completed surveys were received.

2. The results from the first phase were collated and used to prepare a report which participants and others were asked to comment on. All information was presented in an anonymous and unattributed form. The second phase of the survey allowed participants to compare their own answers with the responses of others, and to make changes if they desired or to add any further comments. To capture additional data, reactions were also encouraged from those who did not complete the first stage and the same 77 experts were invited to take part. The second phase ran for three weeks, ending in late October 2003. Out of the original 16 participants, 12 completed the second round. An additional six new participants also took part.

In total, we were able to collect the views of 22 people, constituting a diverse set of the key stakeholders in the field (broadly categorised as: 9 academics, 5 consultants, 2 pressure groups, 3 research institutions, 3 local/central government). It is our view that this sample is broadly representative of wider expert opinion. Considerable effort was made in contacting the expert community, but it is inherent in the nature of complex Delphi surveys that the response rate is low.

Some respondents changed their answers in the second round. For some questions this had the effect of reducing the data range and eliminating the highest and lowest numbers, so there was greater agreement in the responses. However this effect was not seen in all cases, there was little or no movement on some questions and for others the second round responses increased the data range, this increase was, however, in all cases quite small.

### 4.3 Results and discussion

The survey process generated a wide variety of inputs and insights about how progress towards lowering carbon emissions from transport in the UK could be made. In this section the results of the survey are presented. The questions that were put to participants are given first, and the answers received follow.

Q1a. *Do you think the target set out in the Government's Energy White Paper of a 60% reduction in total carbon dioxide emissions in the UK by 2050 is likely to be met?*
63% no
11% yes
26% don't know

The majority of respondents thought that the government's target would not be met. The feeling is that the target is achievable but would be politically and perhaps economically difficult. A strong driver is needed and at present none is apparent. It was thought by one respondent that an increase in the evidence of the adverse consequences of climate change would, over time, provide this driver.

Question 1b. *If you think the 60% target will not be met, what percentage change in emissions do you think is likely by 2050?*
All respondents who thought the government's target would not be met thought that a reduction rather than an increase in emissions would occur. Responses ranged from a reduction in emissions of 10% to 40%. The average (mean) of all answers received was 27% reduction in emissions by 2050.

Question 2. *For the UK transport sector as a whole, by 2050 what percentage change in $CO_2$ emissions from present levels do you think:*
*2a. Feasible?* *2b. Likely?*
It was felt that the change in emissions from the transport sector as a whole could be anywhere between 50% growth to 90% reduction. However, most respondents felt that a reduction in emissions was feasible and would be in the range of 20% to 70%. The mean of all responses gives a feasible reduction of 46% from present levels by 2050. However, it was felt that this reduction will not be realised in full and that the likely reduction would be about half of this. It was felt that the actual reduction was likely to be somewhere in the range of 0 to 60%, with a mean of 23%.

Question 3: *For UK personal land-based transport, by 2050 what percentage change in $CO_2$ emissions from present levels do you think:*
*3a. Feasible?* *3b. Likely?*
The situation for UK personal land-based transport was more optimistic than for the UK transport sector as a whole. Respondents felt that a feasible reduction in emissions for this sector might range from 30% to 90%. The mean of all responses gives a feasible reduction in emissions of 58% from present levels by 2050. Again, it is thought that this reduction will not be realised in full and will depend on what policies are adopted. The mean of all responses gives a likely reduction of 32%, with actual responses ranging from 0 to 75%.

Q4a. *Do you feel a 12.6 MtC target for personal land-based transport by 2050 is appropriate if the 60% reduction for the UK as a whole set out in the Government's White Paper is to be achieved?*
40% of respondents thought the target was appropriate
35% *did not know* if the target was appropriate
25% of respondents thought the target *was not appropriate*

Opinion was divided about whether the target was appropriate, with 60% of respondents answering 'no' or 'don't know'. Several found the question difficult to answer and stated lack of in depth knowledge as their reason for answering 'don't know'.

*4b. If No, please state your own target and explain.*
There was a range of views about what the target should be, with some participants thinking it was unwise to set a target for personal land-based transport in isolation from other sectors.

It was suggested by one participant that the target should be lower, for instance, 5 MtC, as an almost full switch to low carbon fuels, such as hydrogen and biofuels, would be needed to counteract likely increases in air transport emissions. A lower target for land-based transport, it was suggested, would also encourage the development of fuel cell vehicles. Another view was that the target should be

higher, at 16MtC, because reducing reliance on carbon-based fuels is more difficult and costly for moving sources than static sources.

Several participants felt that different sectors are likely to make different rates of progress and that we should adapt accordingly. It was acknowledged that transport faced a unique set of difficulties and that it might make less progress than other sectors. A changing dynamic interaction with other sectors is possible in some cases; for instance, electrolysis to form hydrogen will only be clean if the energy used in the process comes from renewables.

Q5. *By 2050, which level of projected traffic growth (low, central or high) do you think is most likely?*
64% of respondents thought that traffic growth *would be in line with central estimates*
18% of respondents thought that traffic growth *would be in line with low estimates*
12% *did not know* which level of projected traffic growth was most likely
6% of respondents thought that traffic growth *would be in line with high estimates*

The majority of respondents thought that traffic growth would be in line with central estimates. It was reasonably suggested by one participant that some of those who had chosen this option might be doing so to play safe. One respondent who answered 'don't know' felt that growth is not inevitable, instead it is a choice, but high growth is likely if current policies continue. The respondent felt that if road pricing and other measures are adopted then low or zero growth is possible. Other participants felt that traffic levels were unlikely to grow, and that flow saturation and congestion were already limiting traffic growth in some areas of the country.

*Q6. Please rank the strategies by likelihood of occurrence: 1 being the most likely, 3 being the least likely.*

**Table 4.1 Likelihood of strategies occurring**

| Strategy | Technological change (%) | Behavioural/policy changes (%) | Most likely (%) | 2nd ranked (%) | Least likely (%) |
|---|---|---|---|---|---|
| 1 | 100 | 0 | 39 | 50 | 0 |
| 2 | 60 | 40 | 50 | 50 | 0 |
| 3 | 30 | 70 | 11 | 0 | 89 |

Strategy 2, with a balance of 60% technological to 40% behavioural/policy changes, was chosen as most likely to occur. Strategy 1, which relies on 100% technological change, was seen as the next most likely. Only 11% of respondents chose strategy 3 as the most likely to occur, with strategy 1>2>3 being chosen by over three times as many respondents as strategy 3>2>1. It was felt that there is generally more incentive for industry to come up with the technological solution than there is reward for behavioural change by the public. However, there was one respondent who would have chosen an option with a higher percentage of behavioural/policy changes than strategy 3.

*6b. If you feel a different scenario would be more appropriate, please describe your own strategy.*
Participants who detailed their own scenario all envisaged a low contribution from behavioural and policy changes, with these factors accounting for between 10% to 25% of the reduction. Technology was seen as playing a large role in reducing emissions, varying from 75% to 90%. Estimates of average emissions per vehicle kilometre ranged from 70 to 100 ppm $CO_2$. Estimates of the amount of car vehicle kilometres driven in 2050 ranged from 525 to 600bn.

Q7a: *By 2050, what measures are likely to have had the greatest impact on carbon emissions?*
The measures that are likely to have had the greatest impact on carbon emissions by 2050 are given in the Figure 4.1. It is thought that around two-thirds of the impact is likely to come from technological improvements plus car restraint measures. It was felt that measures to alter perceptions of travel would have the least impact on emissions.

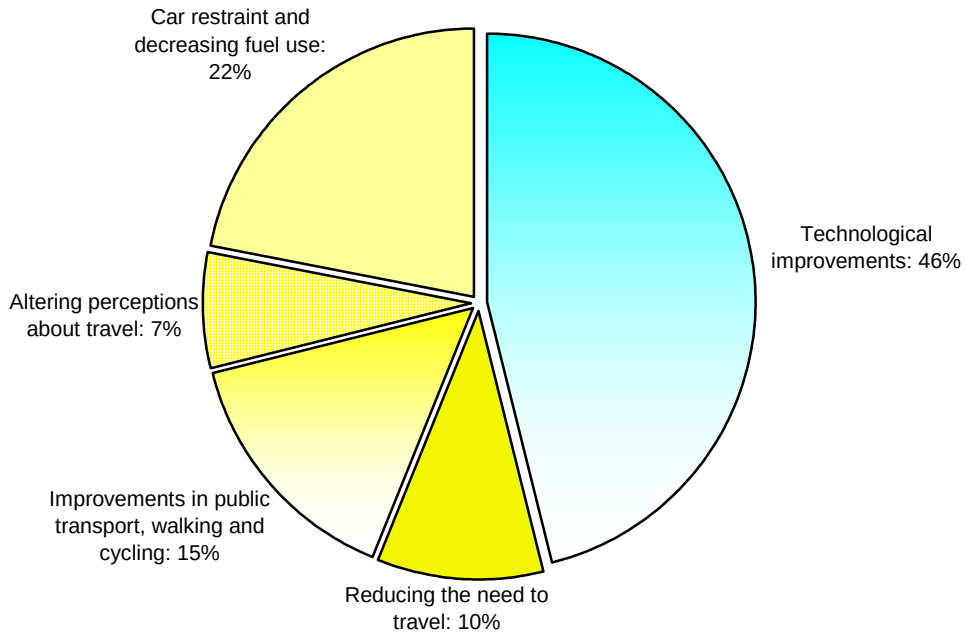



**Figure 4.1 Measures impact on $CO_2$ emissions by 2050**

The technologies that are likely to have had the greatest impact on emissions by 2050 are given in Figure 4.2. Technological succession was envisaged, with improved engine and car design being likely to have an impact initially, then hybrids and latterly, fuel cells. However, there were different views on the potential of fuel cells and concerns about whether their potential would actually be realised. In contrast the majority thought that improved engine and car design and hybrids vehicles would provide real reductions in emissions.

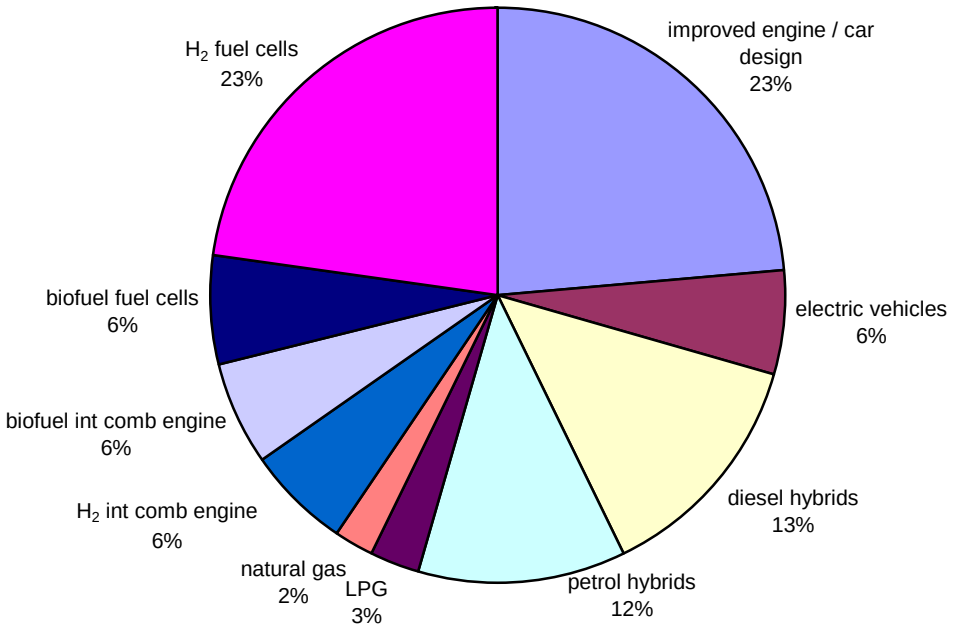



**Figure 4.2 Technological contributions to reducing $CO_2$ emissions**

Support was strong for land use planning, but there were differing views about the capacity of the other measures that could reduce the need to travel to give a real reduction in emissions, see Figure 4.3. For instance, for Internet shopping it was thought that evidence was lacking on the potential to reduce emissions.

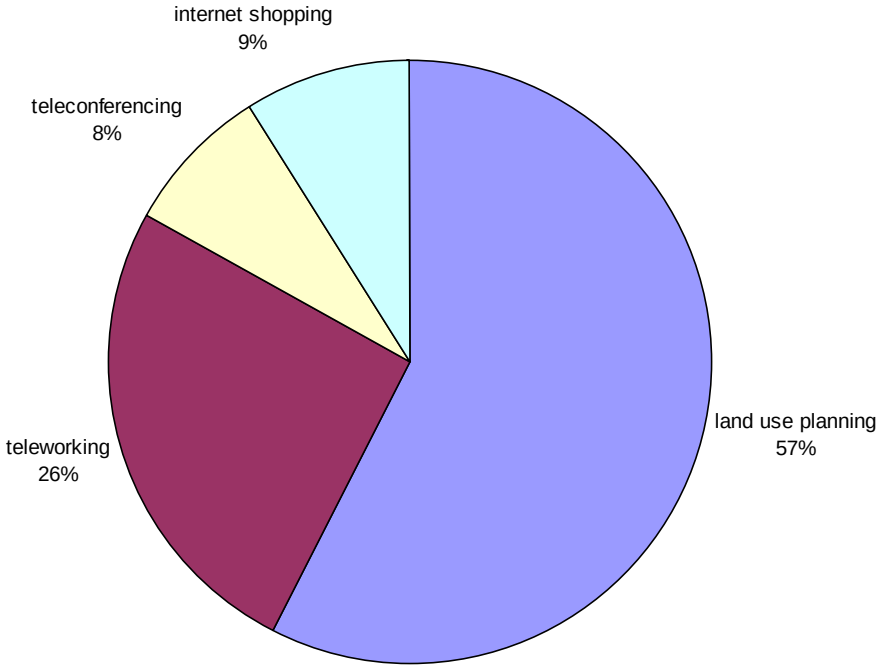



**Figure 4.3 Measures to reduce the need to travel: contribution to reducing $CO_2$ emissions**

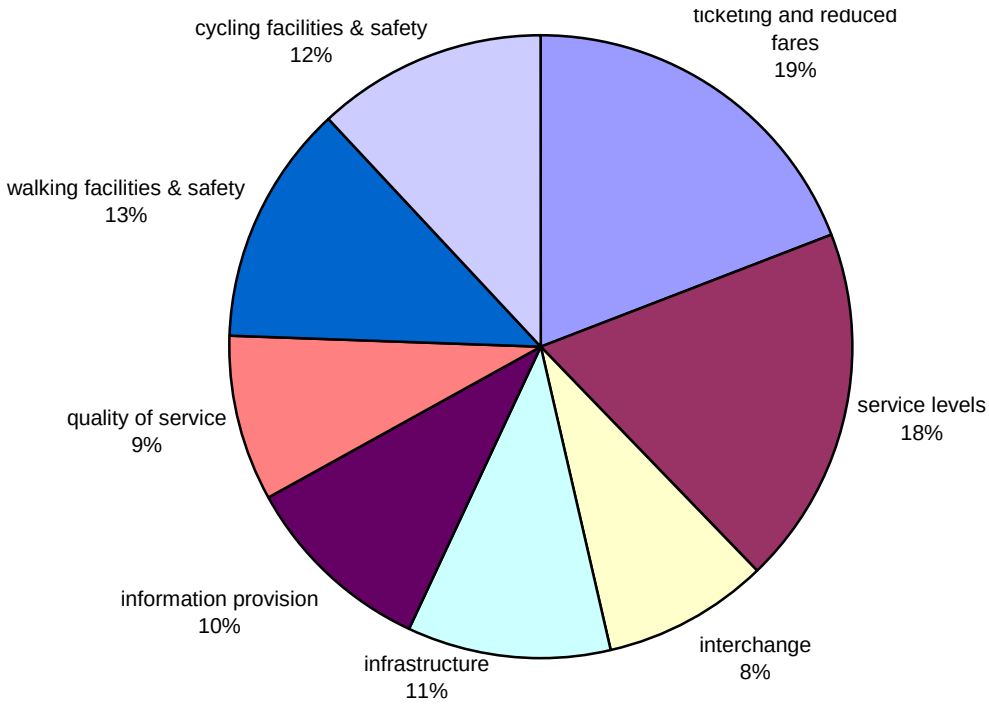



**Figure 4.4 Public Transport, walking and cycling: contribution to reducing $CO_2$ emissions**

With respect to public transport it was felt that there are many incremental measures that could be taken to reduce emissions. Improving ticketing arrangements, reducing fares and increasing service levels were thought to be the most promising, as shown in Figure 4.4. However, it was felt that there is a wide range of measures that could have an impact here, and constructing an integrated package was important.

There was generally low enthusiasm for measures to alter perceptions about travel, but individualised marketing, green travel plans and school travel plans were thought to have the greatest potential to reduce emissions. Compared with the other measures being investigated, it was felt that measures to alter perceptions would have the least impact on emissions.

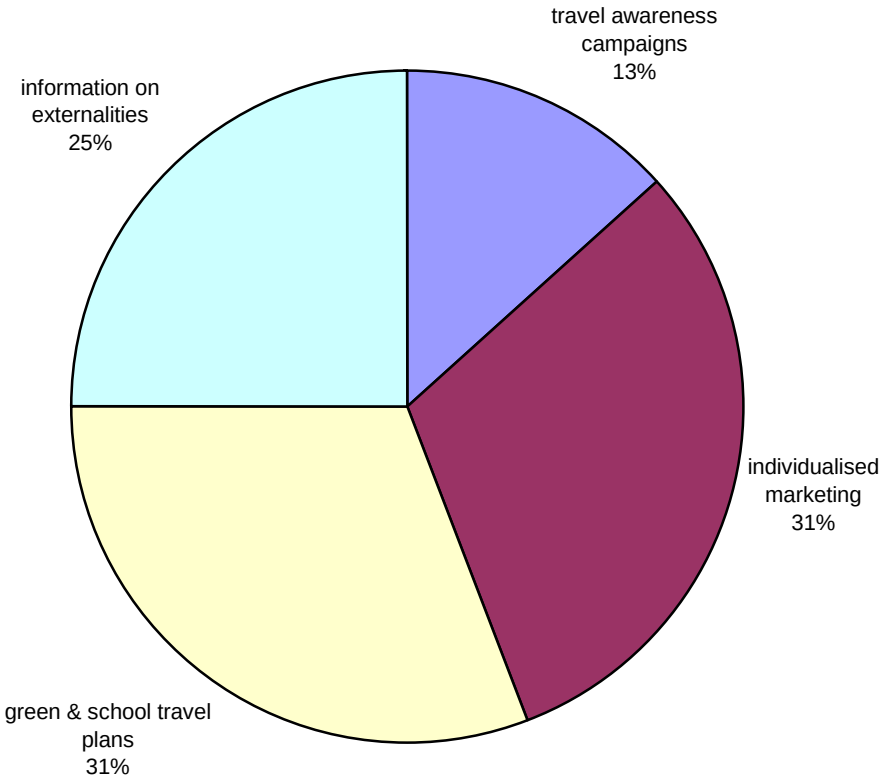



**Figure 4.5 Altering perceptions: contribution to reducing $CO_2$ emissions**

Of the measures to reduce car and fuel use, a national road-pricing scheme and/or increasing the price of fuel were expected to have the greatest impact on emissions. Road pricing in cities and restricting parking spaces are also likely to have significant impacts on emissions, see Figure 4.6.

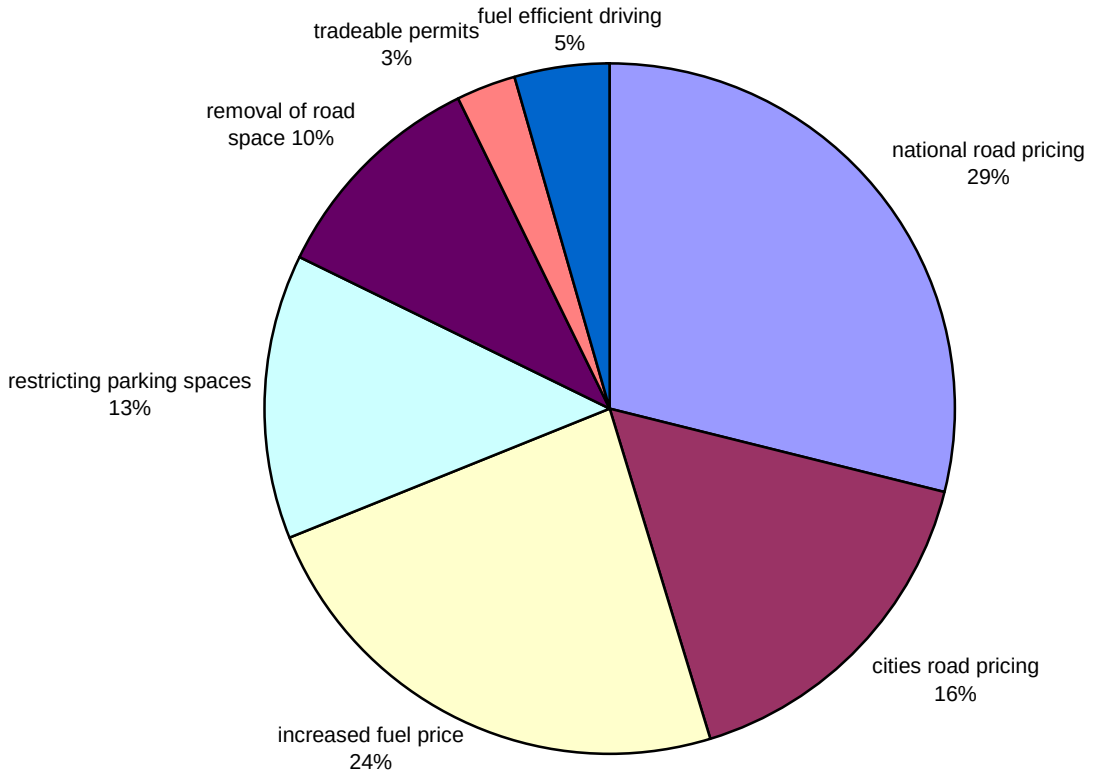



**Figure 4.6 Car restraint and fuel use: contribution to reducing $CO_2$ emissions**

Question 7b: *Do you think that any of the measures in 7a could work against one another? Please explain your answer.*
The primary concern was that improvements in technologies and fuels all have the potential to increase the demand to travel and so increase car use. In this way, progress on the technical side could work against the various measures to cut car use, such as landuse planning and improving public transport. It was suggested, however, that fuel tax could be used to keep this tendency in check, but others felt this was not a politically viable option. Other concerns focussed on competing technologies. For instance, too much emphasis on hydrogen at this early stage could slow down the development of biofuels, and the construction of a dual refuelling infrastructure for biofuels and hydrogen is unlikely. The development of cleaner car technologies will be stimulated by increased purchase of cleaner vehicles, however, the market for cleaner vehicles could be influenced by car restraint measures.

It was suggested that public transport service improvements can lead to a net increase in fuel consumed, however others suggested that well planned improvements (with reasonable load factors) could deliver a net decrease in energy use. It was suggested by one participant that improvements in cycling, walking and public transport modes are obvious competitors and could work against one another, however others felt that they are strongly complementary as a part of a less car dependant lifestyle, and that they are suitable for different journey types.

Teleworking, teleconferencing and internet shopping will tend to work against land use planning aimed at reducing the need to travel because they decrease geographical constraints on where to live, work and shop. Furthermore, these measures were considered as contentious because of a lack of evidence on whether they do lead to overall reductions in travel.

One participant felt that measures to alter perceptions about travel should to some extent reinforce messages about restraining car use (and so, in their words, avoid giving the inaccurate impression that the problem can be solved without car restraint).

*Question 7c: Do you think that any of the measures in 7a could work together synergistically? Please explain your answer.*
It was thought that there are many ways in which measures could work together. One of the main points was that some technologies share similar development needs and that progress in one could be translated to another. For instance, hybrid vehicles and fuel cell vehicles share similar needs to electrics. Some technologies may be compatible with more than one fuel source, for instance diesel hybrid engines can also operate using biofuels.

Infrastructure and public acceptability are other important issues relating to technology. Natural gas vehicles could help speed up the introduction of some types of hydrogen vehicles through infrastructure development and public familiarity. In a similar way, the familiarity of the hydrogen internal combustion engine could be a stepping stone on the way towards public acceptance of hydrogen fuel cells.

A second set of synergies involves changes in behaviour and policy. In general, it was felt that the more unpalatable measures to restrain car numbers should be combined with measures to reduce the need to travel and improvements in other modes, to make them politically acceptable. It was felt that past experience has shown that charging the private motorist more, be it road tolls, fuel prices or parking charges does not in itself have an effective result, unless there are credible, attractive and cost effective alternatives. Reliable, affordable public transport with good connections is important, and measures should be taken to ensure that increasing fuel costs does not result in a rise in bus fares. Improving walking and cycling facilities may increase numbers of leisure walkers and cyclists, but distance is likely to be a barrier to the amount of people choosing to commute by foot or cycle.

Slowing down the decentralisation of urban activities will be important in reducing car use, and land use planning will have a significant role. Improvements in public transport, walking and cycling will work well with travel awareness campaigns and travel plans. A national road pricing scheme and increases to the cost of fuel have the potential to give a number of other measures greater prominence, such as measures to reduce the need to travel. Car restraint and changes to perceptions of travel also complement each other. Measures to change the perception of car use could both reinforce measures to restrain the demand for car use and increase the acceptability of such measures.

One participant felt that the introduction of restrictions on fuel use was inevitable and, because technological advance alone would be unable to lower fuel use sufficiently, car restraint and measures to reduce the need to travel would play the main roles.

Q8a. *Assuming that biofuel technology is adopted, out of the total amount of biofuels used in biofuel-powered vehicles, by 2050 what percentage do you think will be derived from the following sources?*

**Table 4.2 Source of Biofuel**

| Source of biofuel | % of total biofuel used by vehicles | |
|---|---|---|
| | Mean | Data Range |
| Annual crops | 49 | 16 to 80 |
| Woody crops | 48 | 20 to 80 |
| Water-based flora | 2 | 0 to 10 |
| Waste | 1 | 0 to 10 |
| | | |
| *Total biofuels used in biofuel vehicles* | *100%* | |

It was thought that, by 2050, biofuels would derive in roughly similar amounts from annual and woody crops, see Table 4.2. Water-based flora, crop residues and waste (such as municipal solid waste and landfill gas) were also seen as potential sources of biofuel. One respondent felt that annuals are more likely to be used than woody crops as they can be grown quickly on existing set-aside fields. However, one participant felt that the future of biofuel was uncertain and that using arable land in this way will be impractical because it will be needed for growing food crops, as importing food will become prohibitively expensive.

Q8b. *Assuming that hydrogen technology is adopted, out of the total amount of hydrogen used in hydrogen-powered vehicles, by 2050 what percentage do you think will be derived from the following sources?*

**Table 4.3 Sources of Hydrogen**

| Source of hydrogen | % of total hydrogen used by vehicles | |
|---|---|---|
| | Mean | Data range |
| Fossil fuels | 25 | 0 to 65 |
| Fossil fuels with carbon sequestration | 17 | 0 to 40 |
| Electricity derived from renewable sources | 23 | 5 to 60 |
| Electricity derived from nuclear power | 13 | 0 to 60 |
| Plant biomass | 22 | 5 to 65 |
| | | |
| *Total hydrogen used in $H_2$ vehicles* | *100%* | |

It was thought that, by 2050, fossil fuels, plant biomass and renewable electricity were likely to be the biggest sources of hydrogen for hydrogen-powered vehicles. Fossil fuels with carbon sequestration and electricity from nuclear power will play lesser roles. There was, however, some concern about the potential role of renewables, and it was felt that there is unlikely to be enough renewable electricity produced to power transport, and that what was available would be better used for electricity rather than hydrogen.

### 4.4 Conclusions

There was a strong degree of consensus as to whether the 60% emissions reduction target set out in the recent White Paper will be achieved. The majority of experts in the transport field felt that the target for the UK as a whole is unlikely to be met by 2050.

In the personal land-based transport sector, there was a greater emphasis on technology to deliver. Where individuals developed their own strategies, these had a lower behavioural component than Strategies 2 and 3.

Opinions were divided about the emissions reduction potential of new technologies. Generally, respondents from a technical background were more optimistic about the potential of new technologies to deliver. Others felt that over-optimistic thinking about technology and fuel measures could lead to insufficient attention being made to other measures, which could (as one participant put it) allow an evasion of dedication from the 60% reduction target.

There was wide agreement that there is potential for a much larger reduction than is likely to be realised because there is a lack of measures to encourage the production, purchase and use of lower carbon emitting technologies. It was recognised that technological change will be driven in part by policy change

There was general scepticism about the potential of hydrogen. Will it really be the saviour we have been led to believe? There were also significant doubts about the amount of renewable electricity that will be available for hydrogen production.

There was a wide range of opinions about biofuels reflecting the amount of uncertainty surrounding these technologies.

Measures used to reduce emissions from personal land-based transport (or the wider transport sector) cannot be viewed in isolation and should be considered within the wider strategy for UK carbon emissions reduction. The (cost) effectiveness of energy efficiency/carbon reduction measures in transport should be compared with the (cost) effectiveness of measures outside the transport sector, such as in households and industry. There is also the question of other atmospheric pollutants.

A complex picture has emerged from the personal land-based transport sector and a carefully balanced range of measures will be needed to realise deep cuts in carbon emissions. For instance, improvements in technologies and fuels have the potential to increase the demand to travel and so increase car use. In this case, fuel tax could be used to discourage growth in car use. There is a need for greater emphasis to be placed on developing a synergistic package of measures, ones that complement each other and provide counterbalance to any negative effects.

These results support our findings from the literature and modelling exercise. The range of targets offered by respondents who gave their own 5MtC to 16MtC are within the range we developed for testing. The degree of pessimism on the possible contribution from behavioural change is worrying and when combined with doubts expressed on the ability of technology to deliver, strengthens the message that action is necessary to start to change behaviour early.

## 5. HOUSEHOLD RESPONSE

The final element of the study involved survey work to explore households reactions to the need to reduce carbon emissions from transport by 60% and their adaptation behaviour. In order to address this issue we developed a computer based survey tool that had the ability to store and display trip details and the related carbon emissions for each household and to handle changes to trips estimating the resulting carbon emissions. The overall survey methodology involved the following steps:

1. Contact households and gain cooperation
2. Distribute seven day travel diaries to households for completion
3. Collect diaries and enter travel information into the software
4. Conduct interview recording adaptive behaviour and displaying progress towards targets
5. Qualitative and quantitative analysis

Detailed travel diary information was required in order to estimate the households emissions from travel. A week is a reasonable period within which to identify most regular trips and is also a good period over which to consider changes.

In this chapter, we first describe the development of the computer based survey tool in section 5.1. We then move onto the implementation of the experimental survey (5.2) provide a sample interview (5.3) and assess the overall results in section 5.4.

### 5.1 Development of the Computer Based Survey Tool

The object of the software is to allow a household to examine its emissions as a whole and as individuals and to experiment with different ways of reducing emissions and receive comparative feedback. In order to do this the software has to perform two key tasks:

1. The storage and analysis of data
2. The visual display of data and changes in it in a way that respondents could understand

The software is written in Java and uses the Swing API for the graphical user interface. Initially the interview must be configured. This can be done through the user interface but requires up to one hour as the interviewer must configure:

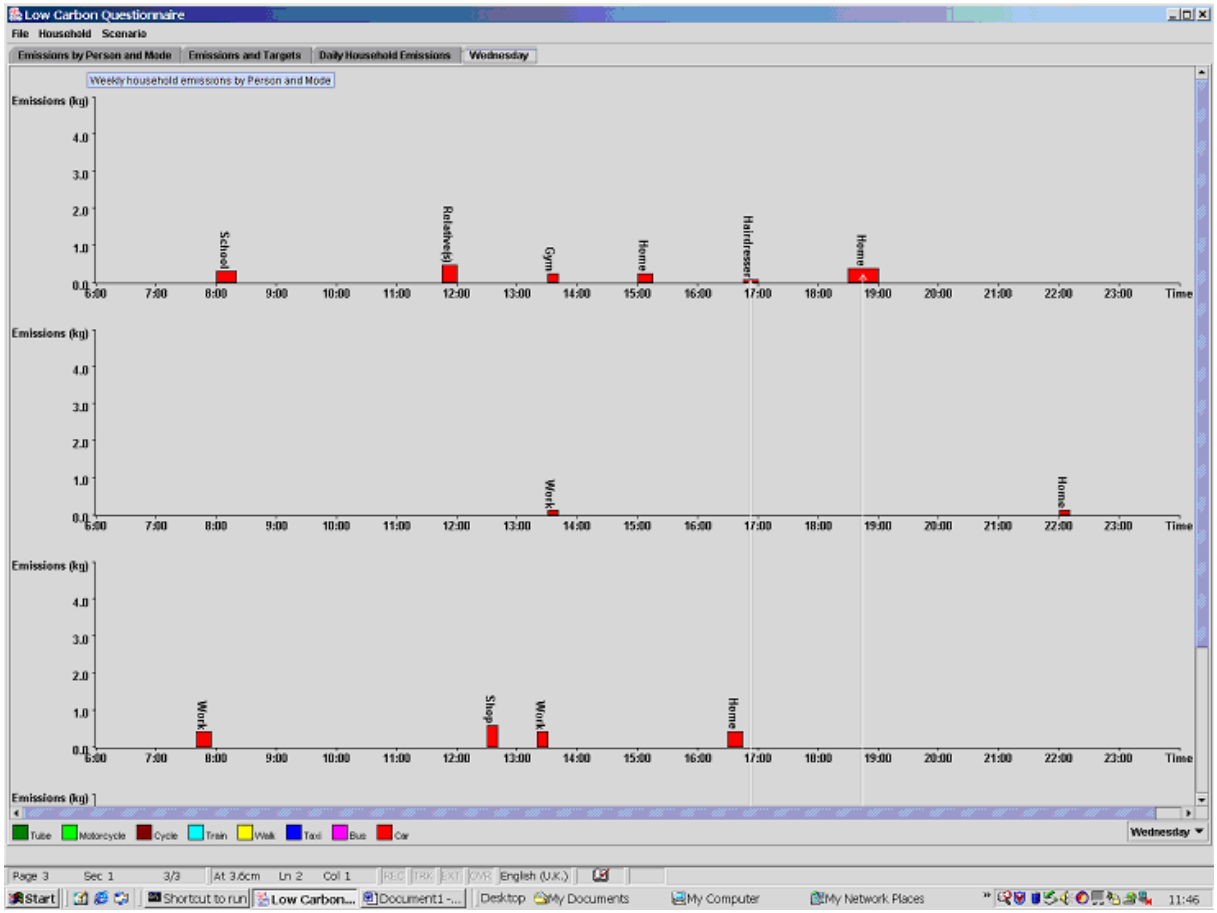
- Origins (termini)
- Destinations (termini)
- People
- Vehicles (emissions for different driving cycles)
- One week's worth of journeys (making up the base "scenario")

In program terminology the "base scenario" is the starting point, the current travel patterns. Once this is input, the interview can begin. The base scenario is copied to the "default" scenario and this defines changes people might make without policy or technological changes. Scenario 1 is based on policy. Scenario 2 is based on technological change and this is reflected in a reduction in calculated emissions.

The GUI allows journeys to be defined partly graphically. Several bar charts are shown together, one for each person. The x-axes (time) line up and show 18 hours worth of journeys, the y axes display emissions in kg. Journeys are shown as bars, in many cases made up of adjoining journey legs. The height of the bar denotes emissions while the width represents journey duration, see Figure 5.1.

A key shows how colour of the bars relates to the mode of each journey leg. The journey legs can be linked between individuals and this is represented by a white arrow. Linking journeys in this way means the emissions are not counted twice in the case of car, motorcycle and taxi journey legs.

**Figure 5.1 Illustrative Diary Page**




The program works out emissions internally based on:

- distance
- mode
- vehicle (car, taxi, motorcycle)
- driving cycle (car, taxi, motorcycle)
- a consideration is made for shared journeys (car, taxi, motorcycle)
- train type (train)
- time of travel (bus)
- marginal or average emissions (train, tube and bus)

The journey tab, just described, can be switched between 7 days. There are 3 other “tabs” which summarise the current scenario:

- Daily Household Emissions shows emissions per day, split by person.
- Emissions and targets show a weeks emissions under each scenario (split by person) as well as two suggested total target emissions.
- The Emissions by Person and Mode tab disaggregates the weeks emissions as in Figure 5.2.

These extra tabs allow the household to zero in on the highest emission journeys.

A final screen compares base scenario journeys with their later scenario equivalents and allows further notes to be added. The program has a single state file as well as several output files for analysis. The outcome of the interview is summarised in terms of performance towards targets in Figure 5.3.

**Figure 5.2 Carbon Emissions per Week by Person and Mode of Transport**

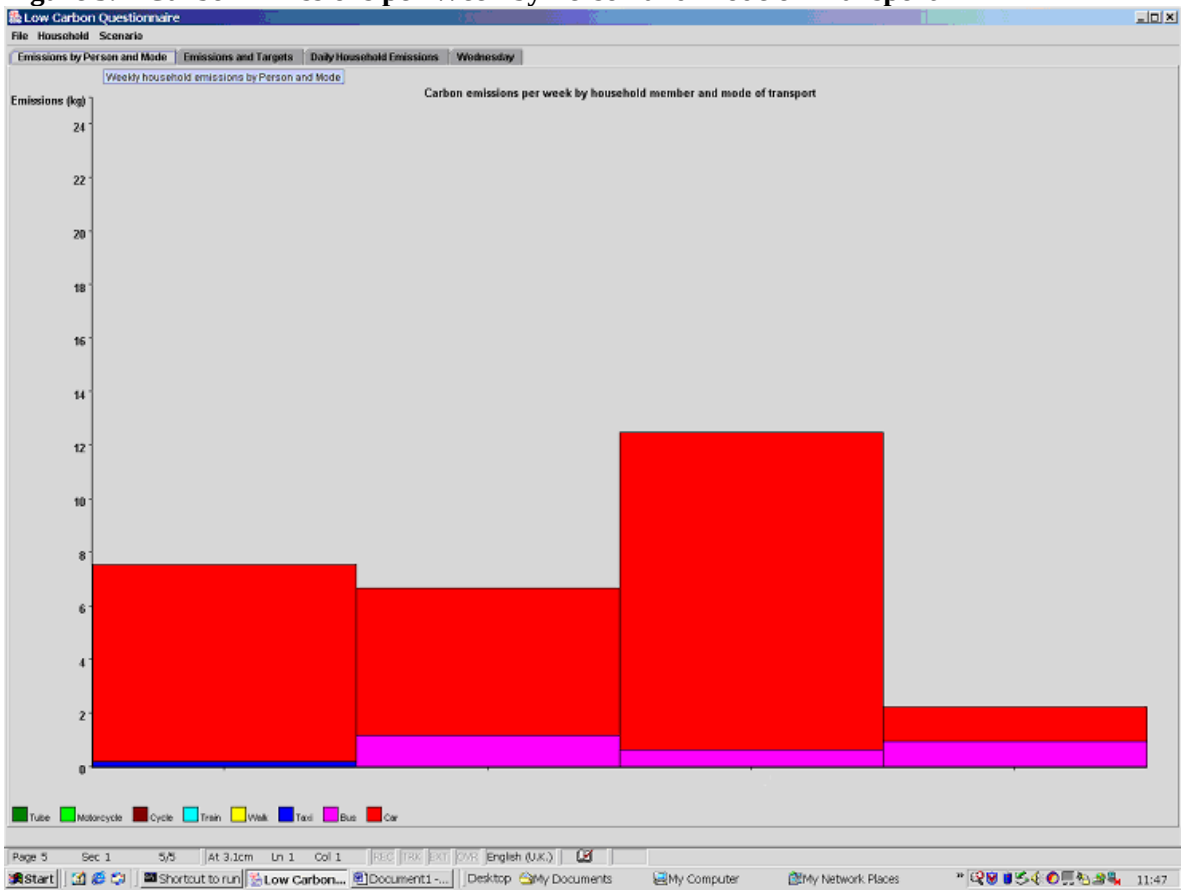
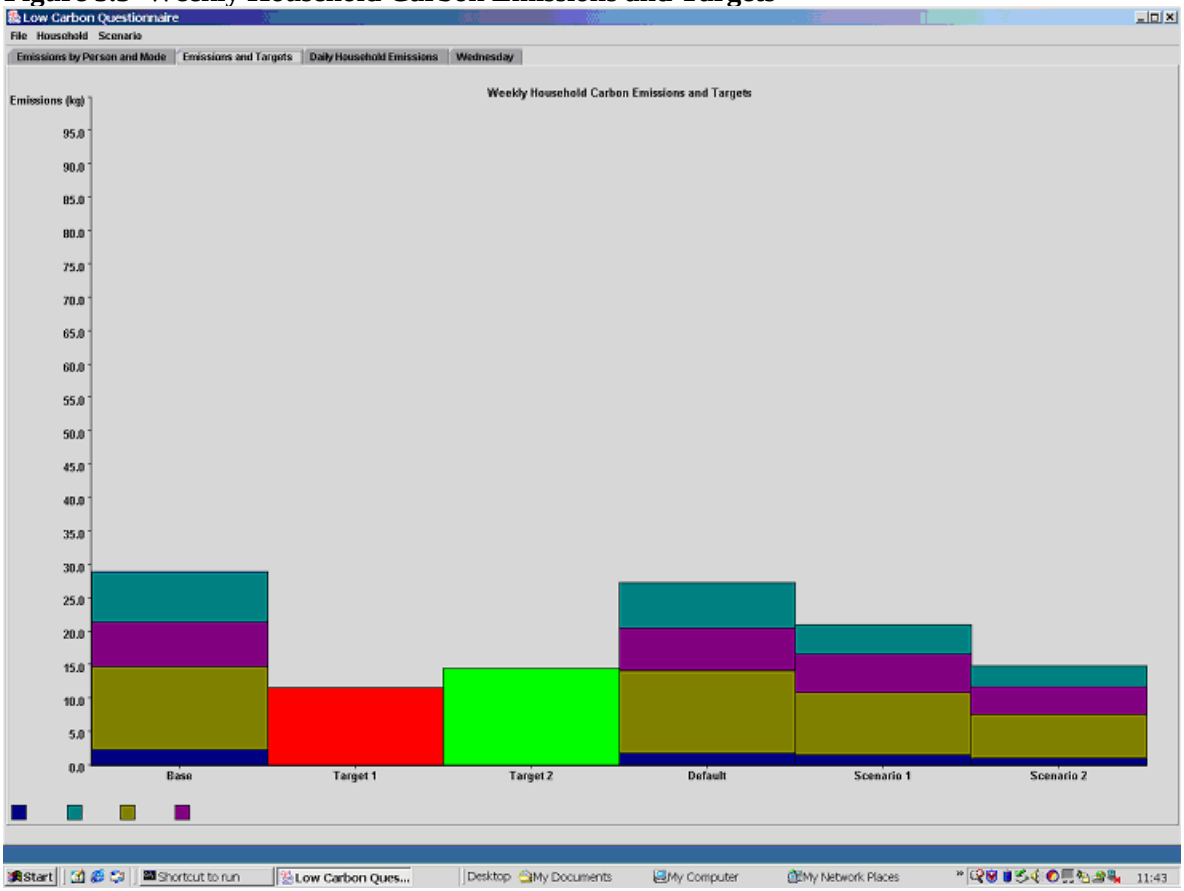



**Figure 5.3 Weekly Household Carbon Emissions and Targets**



## 5.2 Piloting and Survey Implementation

The pilot phases consisted of four interviews these helped to test the design of the software and the running of the interview. As a result for ease of viewing the 24 hour day was reduced to 18 hours (6am to 12am). Initially the display was projected onto a screen so that all household members could see it. However the display was not sufficiently clear, we therefore switched to the use of two monitors, which enabled everyone to see the display. It was also easy for the interviewer to omit to save changes under each scenario, so a pop up reminder screen was included for the main survey. Data entry proved to be a time consuming process and some modifications to allow copying trips and days were made. The interviewer role in both interviewing and recording data was difficult. We considered the use of two interviewers, but found that the modifications to ease data entry together with a growing familiarity with the software and process allowed one interviewer to cope well.

The interviews were conducted during the summer of 2003. It was always the intention to undertake a small number of these experimental surveys to identify the usefulness of the approach as well as for the insights given into possible adaptation to low carbon travel behaviour. As the sample size is small, we decided to target a particular type of household. The decision was made to focus on households with higher than average car mileage as being the households who contribute most to the problem and with the scope to achieve significant reductions.

Households were identified via contacts within the Local Council and Environment Agency and supplemented from the University. The households were then contacted through email or telephone and asked if they would take part in a study to examine how households could reduce their greenhouse gas emissions. The requirements to fill in a travel diary and attend an interview of approximately one hour in length were outlined and a small incentive payment specified.

Once the household had agreed to be interviewed an information pack was sent out. This included a covering letter which provided background information on the project, a household information sheet, a travel diary for each member or the household, a consent form, a card for the households to keep in their car and record mileage, if they wished and a map with location details of ITS.

The household information sheet asked the name and age of members and details of vehicles including age, type of fuel, make and model, to allow the carbon emissions produced per vehicle kilometre to vary according to the characteristics of the vehicle.

The travel diary recorded trips made by purpose, time, distance travelled (households were asked to estimate if unsure), and mode(s) used. For trips by private motor vehicles (car, van and motorbike) households were also asked to record the number of people external to the household who were also transported by the mode e.g. friends or neighbours being provided with a lift to work. The format for the travel diary and the household was a simple, paper based document. It was thought that a paper based rather than a computer based document would result in more people being able to participate. The travel diary was for one week.

The diaries and household information sheet were returned to ITS (pre-paid, addressed envelopes were provided). The information was then input into the computer based survey tool prior to the interview. A paper sheet detailing carbon emissions for walk, cycle, rail and bus (peak and off peak) and specific emissions for the household vehicles was created for the interview.

At the start of the interview the household was provided with a brief summary of the project. It was explained that the Institute for Transport Studies was examining the role the UK transport sector could play in achieving the carbon reductions that were necessary in reducing the worst impacts of global warming. The project was being carried out with the Tyndall Centre for Climate Change Research and funded through three research councils.

The literature review, the setting of carbon emissions targets for the UK personal transport sector, the evaluation of the impacts of behavioural and technological change and the consultation with transport and policy experts were mentioned. It was then explained that the aim of the interview was to elicit opinions from households on how they would reduce their carbon emissions, under their current situation and future more 'favourable' situations. The development and testing of the computer model was also covered.

The households were then shown the computer model (an additional monitor was used to allow all members of household to see a screen). Households were first shown their own weekly emissions and two targets. Target 1 involving a straightforward 60% reduction in the households current transport emissions. Target 2 assumes UK carbon dioxide emissions from all sectors fall by 60%, but transport's contribution to overall emissions increases from current levels. It also assumes that emissions are equally allocated amongst the population. The 60% reduction in this case is from that equal allocation of emissions and so gives a target per person of 3.63kg of carbon per week.

Detailed journey information for every household member for every day of the week was shown. The household was asked to consider how they would alter their travel behaviour under current circumstances in order to move towards the two targets. A sheet with carbon emissions per kilometre for different modes of transport was provided. The computer model was used to record the changes, and the households were prompted about barriers and advantages. It was noted that people often moved into a conditional scenario for example 'I would cycle but there is too much traffic' and the interviewer then suggested that this should be considered under the next scenario (policy). Figure 5.1 shows an illustrative screenshot displaying diary data and Figure 5.2 shows emissions per person per week. During the interview names are displayed on screen, these have been removed.

After the household had completed the emission reductions under their current circumstances the policy scenario (Scenario 1) was considered. Where under current circumstances they had mentioned an 'if' scenario e.g. if there was less traffic, I would cycle, or I would use the bus but it is not reliable or frequent enough this was discussed first and changes made. An attempt was made to quantify what improvements would be necessary e.g. how many buses per hour would you need to use the bus system in Leeds, what do you mean by reliable? Then additional possibilities were introduced:

- Improvements in public transport (bus and rail)
- Use of walking and cycling to replace short car trips
- Working from home
- Use of the internet for shopping trips
- Trip combining
- Car sharing
- Use of most fuel efficient car

An attempt was made to quantify the change necessary to secure a change i.e. what improvements in public transport/cycling facilities would be necessary. The households were also asked to consider the acceptability of these different measures if there was road pricing/traffic restraint in place. The computer model was used to record all changes and additional notes were made.

Once the household had completed as many changes as they thought feasible, a technology factor (Scenario 2) was applied. This reduced all emissions by 30%. A discussion then took place this covered the following issues.

- Why did the household choose their current vehicle – did fuel consumption, carbon emissions, cost of vehicle excise duty play a role?
- How did the household feel about the concept of new technologies for example the use of hybrids or fuel cell cars?
- How did the household feel about the concept of a new fuel for example alcohol based fuels or hydrogen?
- Would you be willing to pay a price premium, if so how much?

Once all changes had been made and discussion of technological change concluded, the household members were thanked for their participation and the interview drawn to a close.

### 5.4 Results

Although the number of households interviewed is small, we have trip data for one week for 37 individuals, travelling a total of 12,602 kilometres, this allows us to look for patterns in the data, summarised in Table 5.1. All households recorded some car travel ranging from 30 kms to 1350kms for the week and all except two made some walk trips. Eight households recorded bus travel. The next most common modes were cycle and taxi each used by four households. Only two households recorded trips by train or motorcycle. We also have one household making trips on the London underground, having spent the diary week at Wimbledon.

Table 5.1 shows that a reduction of 10.6% in car kilometres was achieved under current conditions and bus use increased by over 50%, suggesting that changes are possible within the current system. The other mode to record very large percentage increases, albeit from a low base is cycle, where use doubled and then almost doubled again under scenario 1 where policy measures facilitate behavioural change.

**Table 5.1 Household Kilometres by mode per week**

| Mode | Current | Behavioural change | Scenario 1 |
|---|---|---|---|
| Car | 8963 | 8014 | 7421 |
| Walk | 475 | 510 | 679 |
| Bus | 692 | 1520 | 1587 |
| Train | 1796 | 1170 | 1322 |
| Taxi | 193 | 154 | 135 |
| Cycle | 82 | 164 | 336 |
| Motorcycle | 375 | 386 | 351 |
| Underground | 26 | 26 | 26 |
| Total | 12602 | 11944 | 11677 |

Emissions per household for the current situation and the different scenarios are reported in Table 5.2. Column 1 contains the household identifier and the two carbon reduction targets calculated for the household. The first is a straight 60% reduction in household emissions from transport. The second is derived from our targets in chapters 2 and 3, allowing emissions from the sector overall to grow in terms of share, while the country as a whole reaches the 60% reduction target, the resulting transport emissions are then allocated equally between people. Emissions for households reaching target 1 are shown in bold, those reaching target 2 in italics and those reaching both in bold italics.

Under current conditions a very small overall reduction in emissions is achieved. Although fewer car journeys are made, many of these journeys are switched to bus. Under current conditions the average emissions per bus passenger are not markedly better than those for car. This partly explains the small impact on emissions 2.9% for a 10.6% reduction in car use. Under scenario one most of the switching from car is to other modes including cycle and the resulting changes in emissions are greater, car use has now fallen by 19.2% and emissions by 16.4%. None of the households reach their targets under current or improved scenarios. Once efficiency and technological gains reduce emissions by 30% targets become more achievable.

Households who could envisage life style change tended to favour the following modes and solutions (number of households in brackets):

- Walk instead of car (3)
- Cycle *if* there were less traffic (3)

- Use public transport instead of car *if* reliable and cheaper (8)
- Telecommute *if* employer would accept it (4)
- Trip combining (1)
- Use of households most fuel efficient car (2)

**Table 5.2 Carbon emissions by household and scenario kilogrammes per week (percentage reduction in emissions from current in brackets)**

| Household and targets | | | Current emissions | Revised | Scenario 1 | Scenario 2 |
|---|---|---|---|---|---|---|
| 1 | 9.28 | 7.25 | 23.19 | 23.14 (-0.22) | 22.14 (-4.53) | 15.50 (-33.16) |
| 2 | 18.53 | 14.51 | 46.33 | 45.34 (-2.14) | 40.35 (-12.91) | 28.24 (-39.04) |
| 3 | 11.58 | 14.51 | 28.95 | 27.33 (-5.60) | 21.04 (-27.32) | 14.73 (-49.12) |
| 4 | 6.67 | 10.88 | 16.67 | 16.47 (-1.20) | 14.02 (-15.90) | *9.81 (-41.15)* |
| 5 | 6.80 | 3.63 | 17.00 | 16.25 (-4.41) | 13.66 (-19.65) | 9.56 (-43.76) |
| 6 | 3.35 | 3.63 | 8.37 | 8.25 (-1.43) | 8.25 (-1.43) | 5.78 (-30.94) |
| 7 | 6.48 | 7.25 | 28.5 | 28.5 (0) | 14.76 (-48.21) | **10.34 (-63.72)** |
| 8 | 5.49 | 7.25 | 13.71 | 13.71 (0) | 12.69 (-7.44) | 8.88 (-35.23) |
| 9 | 11.59 | 7.25 | 28.98 | 22.81 (-21.29) | 22.81 (-21.29) | 16.71 (-42.34) |
| 10 | 15.67 | 14.51 | 39.18 | 39.18 (0) | 33.73 (-13.91) | 23.61 (-39.74) |
| 11 | 5.07 | 3.63 | 12.67 | 12.67 (0) | 6.69 (-47.20) | ***4.68 (-63.06)*** |
| 12 | 3.84 | 3.63 | 9.61 | 9.61 (0) | 9.61 (0) | 6.73 (-29.97) |
| 13 | 16.31 | 14.51 | 40.77 | 40.08 (-1.69) | 35.70 (-12.44) | 24.99 (-38.70) |
| 14 | 12.24 | 14.51 | 30.59 | 30.33 (-0.85) | 28.06 (-8.27) | 19.64 (-35.80) |
| 15 | 10.70 | 7.25 | 26.76 | 26.76 (0) | 26.76 (0) | 18.73 (-30.01) |
| Total | 148.52 | 134.20 | 371.28 | 360.43 (-2.92) | 310.27 (-16.43) | 217.93 (-41.30) |

These households tended to have a level of environmental awareness and a willingness to change. Respondents also found the computer display screens informative in revealing the number of short trips made by car or in illustrating the gap between current emissions and the targets.

There were also households for whom change in the current circumstances was not seen as possible: visiting family members in remote areas, transporting heavy items and trips for leisure.

People did seem to be willing to try new power systems for example hybrids and fuel cells and new fuels for example biofuels and hydrogen. While there was little enthusiasm to paying a price premium for a more environmentally friendly vehicle, if this also resulted in operating cost savings, the attraction grew.

No targets were met until the technological change was introduced, when one household met both their targets and another met the 2nd target. However, under a policy scenario favouring behavioural change, savings of over 14% were achieved and with the addition of technological improvements in efficiency of around 30% this increases to nearly 40%. This is close to the Delphi outcome on feasible reductions of around 46%.

### 5.5 Conclusions

We have developed a survey tool which allows households to view their trip making behaviour and the resulting carbon emissions and change their behaviour in an effort to reduce emissions.

Evidence from a small number of household surveys suggest that even households which exhibit a willingness to change their behaviour would find it difficult, even under supportive scenarios to achieve a 60% reduction in carbon emissions from transport. This suggests that a higher proportion than 30% of savings will have to come from technology, which matches our findings from the

literature, modelling and expert consultation. However, there is an ability to change, and this needs to be supported through improvements to existing provision and incentives to switch.

## 6. CONCLUSIONS

### 6.1 Targets

A literature review suggested two stabilisation targets for $CO_2$ of 550 ppm and 450 ppm. For the UK this implies total emissions in 2050 of 62.2 and 31.1 MtC respectively. A review of five key studies containing future scenarios for $CO_2$ emissions for the UK was used firstly to establish feasible 2050 baseline projections for the UK and secondly to examine possible ways in which reductions could be achieved.

Two approaches were used to estimate the contribution of transport to total emissions in 2050:

- stabilisation at the current level of approximately 26%
- an increase to approximately 41% derived from the studies reviewed

These percentage contributions were then applied to the 62.2 and 31.1 MtC emission targets and the emission reductions needed from transport's 1997 levels calculated. The results gave a range of targets from 8.2 MtC to 25.7 MtC and a range of reductions from 13.3 MtC to 30.8 MtC. Even the weakest of these targets implies a significant reduction from current emission levels. When set against the forecast growth in emissions shown in Table 2.1, the weakest target would require a 50% reduction from trend by 2020.

The targets derived for the land based passenger transport sector ranged from 4.9MtC to 15.4MtC reflecting the use of two stabilisation targets and two levels of contribution from transport.

### 6.2 Strategies

This section considers conclusions from the study as a whole.

Technology cannot be the only solution to reducing $CO_2$ emissions. There is considerable uncertainty as to the level of reduction that can be delivered in terms of vehicle technology and securing carbon neutral sources of hydrogen. While it is possible that technology will deliver clean carbon neutral fuels for the future (RAC, 2002) the uncertainty is great. The High Level Group for Hydrogen and Fuel Cells (2003) do not see fuel cells becoming the dominant technology in transport before the 2040s in their "skeleton" proposal. While the IPCC (2001c) indicate that in order to achieve stabilisation at 450ppm world emissions must start to fall in the next 20 years. Reliance on technology to deliver is risky firstly due to uncertainty, secondly as efficiency gains will be offset to some extent by increased demand and thirdly it is important that reductions are secured sooner rather than later if key stabilisation targets are to be achieved.

Clear price signals to car users appear to be the most effective measure alongside technological change. The use of the price of conventional fuel as the instrument will also give an additional incentive to travellers to switch to more efficient vehicles or to adopt new technologies earlier than would otherwise be the case. However it should be recognised that measures can "rebound" in a way that offsets direct benefits. For example improved fuel efficiency or cheaper fuels (perhaps encouraged through lower tax levels) lead to a fall in the cost of travel which will then lead to an increase in the number of trips. Telecommunications facilitates home working but leisure or shopping trips may replace commuting trips.

Improvements to passenger transport, cycling and walking facilities, the siting of facilities closer to home and the increased use of telecommunications will also be required if change is to occur on a sufficient scale. Shifting trips from car to public transport may not secure significant reductions in $CO_2$ with the current vehicle fleet and load factors. In chapter 5 we saw that a significant switch of trips from car to bus did little to reduce emissions. A step change in emissions from passenger transport is required. An additional confounding feature of passenger transport is that improvements will attract trips from walk and cycle and generate new trips. This again reinforces the message that

behavioural change beyond modal shift between motorised modes is required, including reductions in trip making and reduced lengths of journeys that will facilitate the use of non-motorised modes.

The household surveys suggest that even households which exhibit a willingness to change their behaviour would find it difficult, even under supportive scenarios, to achieve a 60% reduction in carbon emissions from transport. This suggests that a higher proportion than 30% of savings will have to come from technology, which matches our findings from the literature, modelling and expert consultation. However, there is an ability to change, and this needs to be supported through improvements to existing provision and incentives to switch.

Existing knowledge is stronger on technology and pricing effects than on measures relating to telecommunications, service quality, walking, cycling and land use. However, even for these, we cannot be certain that current elasticities will apply in fifty years time.

Our scenarios have been constrained by political and social acceptability, hence the relatively late introduction of both pricing and improvements to public transport. However, if these measures were introduced earlier, the required increases to say petrol prices would be less extreme as the traffic growth in the years prior to the 2010 and 2015 implementation dates could be avoided.

### 6.3 Policy Implications

Clearly meeting the targets will require major changes over the coming years both in the nature of transport and in the way that transport is perceived and utilised by individuals and organisations alike. It is likely that changes in technology will go some way towards achieving the targets, but it is questionable whether this alone will be enough, especially if the wider international context of change is taken into account. Lag times between the widespread uptake of new technologies in the UK or other developed countries and the rest of the world are likely to be considerable. Even in the UK significant technological change will take some time and given the residence times of GHGs in the atmosphere it is imperative that reductions in carbon emissions are achieved sooner rather than later. Technology will achieve efficiency gains but these are likely to be offset by traffic growth (IPCC, 2001b, CfIT 2003).

An alternative to a complete reliance on technological change is to start to implement schemes which are aimed at changing transport behaviour. The scale of such changes are likely to be large and to require considerable lifestyle adaptation, though the advantage of such changes is that they could, at least theoretically, be implemented on a quicker timescale than technological change. Another advantage is the potential for synergy in introducing measures that may reduce other transport related externalities, particularly congestion (Proost, 2000). However, major barriers exist to implementing such developments in particular the need (still) to take the potential impacts of climate change seriously at both a political and individual level and for government to be willing to take a lead in promoting and enforcing a more sustainable transport future. The Energy White Paper (DTI, 2003a) only considered technological change with respect to transport and made no mention of behavioural change. The 10 year plan for transport (DETR, 2000b) even if fully implemented will serve only to stabilise emissions from transport. There is considerable doubt as to whether many of the 10 year plan measures will be implemented within the time frame, especially the road user charging and work place parking levy schemes envisaged and the provision of sufficient rail capacity to carry the planned 50% increase in passenger miles (May et al, 2002). The Sustainable Development Commission (2003) estimate that the Governments 20% reduction target for $CO_2$ will not be met and consider savings from the 10 year plan “insecure”.

Our modelling work and consultation with experts reinforces the message that technology alone cannot provide the answers. More rapid progress on measures to change behaviour is required, if we delay for a few years and then decide that behavioural shift is essential, the measures required become more extreme and hence more difficult to implement. Modal shift to public transport is a part of the solution, but emissions from public transport need to be addressed if significant reductions in $CO_2$

emissions are to be achieved. Pricing measures to restrain car use and encourage the take up of more efficient or alternatively fuelled vehicles are seen to be most effective in inducing behavioural shift. It appears that model shift alone will not suffice and moves to reduce both the need and the desire to travel are required. A critical step will be in informing the public of the nature of the problem and the need to change and creating a desire to change, perhaps through the promotion of lifestyle change linked to improved quality of life.

### 6.4 Future Research

We have developed targets and strategies for one area of transport. A critical requirement is to undertake a similar exercise for freight and air transport. Road transport is the dominant freight mode and haul lengths are increasing. Demand for air transport in the UK is forecast to grow to levels twice or three times as high as today by 2030 (Department for Transport 2003a). Current emissions attributed to UK international flights are around 8MtC, as opposed to 1MtC for domestic flights (DTI, 2003a), while $CO_2$ emissions attributed to international aviation have increased by 87% between 1990 and 2001 (Baggott et al 2003). Further rapid increases are forecast, to between 18 and 20MtC by 2030 (DfT 2002), posing a serious challenge for a low carbon transport strategy, given our targets for the whole transport sector of 8.2 to 25.7 MtC by 2050. The omission of international aircraft emissions from climate change agreements is a weakness.

Emissions from passenger transport need to be addressed, if modal shift is to be a focus of policies to reduce $CO_2$ emissions. Average emissions per passenger kilometre for passenger transport modes, especially bus with the current vehicle fleet and load factors are not necessarily better than those for multi-occupancy fuel efficient cars. There have been a variety of UK based trials of different bus fuels and three hydrogen fuel cell buses are about to start work in London. However, there is no clear drive to improve efficiency quickly. The Governments continuing review of bus subsidies (Department for Transport 2003b) provides an opportunity to identify incentives to operators.

More detailed interactive research with users on the feasibility of the strategies, with a larger more representative sample is required. The strategies are based on familiar measures, many of which form part of Government policy, albeit at a different scale (Department for the Environment Transport and the Regions, 2000b). However, it is challenging for households to consider how they might respond to a very different environment over a long period of time. More detailed specification of what the strategies would mean for them locally may be of use here.

There are many developments in technology and its use and elsewhere, where the net impacts on transport demand and supply are uncertain. Further work is required to establish how new technologies are being used and their final impact on transport demand. A key issue here is the use of telecommunications to replace work trips, commute trips and shopping trips. Where these trips were previously made by car, is there a net reduction in car mileage or will the car be used by another household member for trips previously made by public transport or are additional trips generated? Even if the net transport effects within the household are positive, teleshopping will have implications for the logistics industry and teleworking will imply additional heating and lighting in the home which may be offset by savings in the workplace.

We have focussed on land based passenger transport in this study. A critical step in determining pathways to low carbon transport is to fully consider interactions with other sectors in the economy. How would other sectors have to adapt to facilitate low carbon transport? How could low carbon transport interact positively with changes in other sectors to reduce emissions. Key questions are:

- What will the impacts of teleshopping be on the freight and logistics industries?
- How will homes be designed in the future to accommodate a range of possibilities such as teleworkers, deliveries, cycle parking and vehicle refuelling?
- How can buildings and land use adapt to facilitate walking and cycling?

- Can the education sector adapt to allow children to walk to school through moving to local catchment areas? If this were to happen could parents be persuaded to allow their children to walk or cycle to school?
- Can access to health facilities be arranged locally to where the person happens to be at the shops, school, work or home?
- How should large facilities used by people from a wide area be located, hospitals, shopping centres, leisure facilities?

Assuming we could move to a low carbon transport system, what are the implications for quality of life? If low carbon transport is actually or is perceived to be restrictive, difficult and expensive then it will be more difficult to promote change. However, low carbon transport could be linked to attractive lifestyles, involving less stress and a cleaner, safer environment. Research then is needed into how people perceive their quality of life to be impacted by transport and ways in which they would like this to change.

There are many such questions and for transport the need for integrated thinking for the future is clear. While progress can be made in the transport sector alone, integration with policies in other sectors will be necessary to avoid offsetting effects and to reinforce measures.

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The inter-disciplinary Tyndall Centre for Climate Change Research undertakes integrated research into the long-term consequences of climate change for society and into the development of sustainable responses that governments, business-leaders and decision-makers can evaluate and implement. Achieving these objectives brings together UK climate scientists, social scientists, engineers and economists in a unique collaborative research effort.

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