The UK MARKAL Documentation

Transport Sector Module

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Chapter 8: Transport Sector Module

1. Introduction

This chapter describes the methodology used in modeling the transport sector and its key data sources and underlying assumptions. Section 2 describes the overall module structure and how various technologies are characterised in MARKAL. Section 3 describes the details of individual transport technologies and their relevant data sources. Section 4 describes the brief notes on calibration of the base year data and other constraint in this module. Section 5 discusses limitations and uncertainties. Appendix T-I provides details of the main stakeholder workshop undertaken as part of the transport sector data consultation process.

2. Transport Module structure

The transport module includes details of transport sector energy service demands [in billion vehicle kilometers (BVkm)] for various modes of transport and their corresponding end-use vehicle technologies. In addition to these data, it has a number of fuel distribution networks to track fuel use by mode of transport. Figure T-1 illustrates a simplified version of the module structure. A detailed structure of technology/fuel coverage in the transport module are summarised in Figure T-2.

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Figure T-1: Simplified structure of the Transport sub-module
Figure T-2: Transport Technology Module Structure

NB. Changes in this version of the RT module are indicated by *new* or *x* (where a technology has been removed).
### 2.1. Energy service demands

In transport sector, ten categories of energy service demand are defined in billion vehicle kilometers (BVkm), and provided at 5 year increments between 2000-2070. Table T-1 shows the list of transport energy service demands.
Where the transport sector uses electric vehicles, including rail, then the time of occurrence of energy service demand within the six seasonal periods can be specified as an additional input parameter. This enables accounting of the contribution of electric demand to the grid (see Chapter 5 for more details). However, in the current model, all demands are assume to be flat, i.e. uniformly distributed throughout the year.\(^1\)

Table T-1: Transport energy service demand by category with base year 2000 data

<table>
<thead>
<tr>
<th>Type of transport energy service demand</th>
<th>Base year 2000 (BVkm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Transport – Domestic (TA)</td>
<td>0.15</td>
</tr>
<tr>
<td>Bus travel (TB)</td>
<td>5.61</td>
</tr>
<tr>
<td>Car travel (TC)</td>
<td>354.00</td>
</tr>
<tr>
<td>Rail freight transport (TF)</td>
<td>0.18</td>
</tr>
<tr>
<td>Heavy goods vehicle (HGV) (TH)</td>
<td>32.94</td>
</tr>
<tr>
<td>Air Transport – International (TI)</td>
<td>**</td>
</tr>
<tr>
<td>Light goods vehicle (LGV) (TL)</td>
<td>58.53</td>
</tr>
<tr>
<td>Rail passenger transport (TR)</td>
<td>0.43</td>
</tr>
<tr>
<td>Ship Transport (TS)</td>
<td>28.58</td>
</tr>
<tr>
<td>Two-wheeler transport (TW)</td>
<td>4.88</td>
</tr>
</tbody>
</table>

* Currently excluded from the analysis

2.2. Demand (Vehicle) Technologies

To meet the different modes of transport energy services, a number of vehicle technologies are included in the model. The current MARKAL model, in being developed and updated from the previous version (as used for the EWP 2003), includes a number of new technologies. There have been developments particularly in areas of hydrogen and fuel cells, with fuel cells vehicles utilising fuels other than hydrogen considered unlikely for transport applications (with the possible exception of methanol). In addition, developments have indicated that hydrogen fuel cell rail vehicles might be a viable possibility in the longer term as a replacement for diesel powered traction. Other significant changes include:

- Inclusion of 2-wheelers in the model;

\(^1\) If not specified, then model algorithms assume electric demand for the transport sector is uniform and evenly distributed through time (diurnally and seasonally). In case of plug-in electric cars, the model assumes that cars are charged and used simultaneously.
• Inclusion of diesel hybrid light duty vehicles (several of which are already in development by auto manufacturers);
• Addition of LPG and of flex-fuel gasoline/ethanol light duty vehicles;
• Addition of plug-in hybrid petrol and diesel cars and LGVs. These have larger batteries and electric engines than regular hybrids allowing for grid charging and longer range and better performance under electric power only;
• Inclusion of gas-to-liquid/Fischer Tropsch diesel (FT diesel), including the subset of so-called 2nd Generation biofuels - BTL diesel (biomass-to-liquid diesel, produced via biomass gasification and Fischer-Tropsch, such as VW’s ‘SunFuel’);
• Splitting Rail demand into Rail Passenger and Rail Freight demand;
• Addition of international aviation technologies and demand.

There are a number of key data parameters that are required to characterise the transport vehicle technologies. In general, these were provided at 5 yearly intervals for the model horizon. They include:

• Technical efficiency of vehicle (MJ/km)
• Capital cost of vehicle (£)
• Annual fixed O&M cost, (£/a)
• Vehicle lifetime (y);
• Annual kilometres usage (to ensure that the model characterises the number of vehicles in the system to meet the required energy service demand)
• Optional technology specific discount factor (see Chapter 2, Appendix 2-I for details)

The different road vehicle technologies are vintaged to ensure that improvements in vehicle performance and cost reductions are properly reflected in future years. In other words, an petrol ICE vehicle in 2020 will be available in the model separately to the one available in 2010.

The emission associated with the fuel used in the vehicle is tracked at the fuel supply level (see Chapter 4).

3. Detailed overview of data and Assumptions

3.1. Energy service demands

The base year 2000 energy service demands for ten transport modes were calculated and calibrated to known estimates of transport fuel use based on UK energy statistics (DUKES, 2005) (also see Section 4). For the subsequent periods (2005-2070), they were estimated based on projection information from the Department for Transport. Table T-1 shows the energy demand for the base year and their growth relative to 2000 levels is shown in Figure T-3. The energy service demands used were estimates of actual energy service demands – growth in terms of vehicle kilometers.
Input data were concerning vehicle technologies – providing the above energy service demands – were collected from a wide variety of sources (including publicly available UK and international reports, web searches, government and industry experts, etc.). Some prominent sources of data include:

- Recent UK Government studies/reports (e.g. Aviation White Paper ‘The Future of Air Transport’, December 2003) and national statistics;
- Other recent UK reports (e.g. ‘A strategy towards sustainable development of UK aviation’, Sustainable Aviation report, June 2005);
- SMMT (e.g. collected data on the average CO\(_2\) emissions of new cars), other industry organisations (e.g. Rail Research UK, Civil Aviation Authority);
- EC project reports (e.g. JRC/CONCAWE Well-To-Wheels study, 2004 and its 2005 update; ‘Measuring and preparing reduction measures for CO\(_2\)-emissions from NI vehicles’, by TNO Automotive for EC DG Environment, 2004)
- IEA publications (e.g. ‘Prospects for Hydrogen and Fuel Cells’, 2005)
- US studies (e.g. from US DoE, Argonne National Laboratory, NREL, etc.)

A full list of major sources used is listed in the references section. The following sub-sections discuss the major assumptions and methods used to update the transport technology module dataset.
3.2. General principles and assumptions

The following basic methods and assumptions were used in the development of the dataset (in many cases relevant to road transport only):

- All costs data were converted to year 2000 £s when appropriate.
- On-road/in service efficiencies were used in the model for all vehicles. For cars, where relevant we converted from test-cycle data using a factor of 1.18 from the IEA-SMP (2004) modelling work.
- Cars were often used as basis for estimation of relative changes to comparable technologies in other modes, where specific information was unavailable.
- In scaling to different technologies/modes assumptions on Motive Power (MJ/km), Engine Power (kW) and Vehicle range (km)/tank size (MJ) were utilised (plus other factors) wherever appropriate.

The following data tables provide an overview of the key data used in the transport module. Cells have been highlighted in different colours to indicate the form of cell contents. A brief note on colour shadings and a qualitative classification of data sources is shown in Table T-2.

Table T-2: Classification of transport module data sources

<table>
<thead>
<tr>
<th>Colour shades</th>
<th>Quality of data sources</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yellow (brown text)</td>
<td>LINKED</td>
<td>Cell linked directly to another in the datasheet</td>
</tr>
<tr>
<td>Green</td>
<td>Good</td>
<td>E.g. EC or UK government reports, high profile studies.</td>
</tr>
<tr>
<td>Orange</td>
<td>Medium</td>
<td>E.g. Professional industry opinion/estimate or lower profile studies/website</td>
</tr>
<tr>
<td>Violet (brown text)</td>
<td>Calc</td>
<td>E.g. Calculation from other datasheet values/cells</td>
</tr>
<tr>
<td>Sky blue</td>
<td>Estimate</td>
<td>E.g. Estimate in absence of data/information</td>
</tr>
<tr>
<td>Light blue</td>
<td>Other</td>
<td>E.g. Old data/estimate or based on calculation from other data</td>
</tr>
</tbody>
</table>

For example, Table T-3 shows the list of key data assumptions made for vehicle technologies, e.g. annual use of vehicle km, ICE power, tank size/range, capacity and load factor.
Table T-3: General Assumptions on vehicle technologies

<table>
<thead>
<tr>
<th></th>
<th>Annual km</th>
<th>ICE, kW</th>
<th>Tank size, MJ</th>
<th>Tank size, litres</th>
<th>Normal av. range, km</th>
<th>Capacity</th>
<th>Load Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 Wheels</td>
<td>5,536</td>
<td>19</td>
<td>851</td>
<td>27</td>
<td>555</td>
<td>2</td>
<td>55%</td>
</tr>
<tr>
<td>Car</td>
<td>14,481</td>
<td>75</td>
<td>1,743</td>
<td>55</td>
<td>601</td>
<td>4</td>
<td>39%</td>
</tr>
<tr>
<td>Van</td>
<td>20,272</td>
<td>75</td>
<td>2,144</td>
<td>60</td>
<td>544</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HGV</td>
<td>54,000</td>
<td>210</td>
<td>9,828</td>
<td>275</td>
<td>855</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bus</td>
<td>63,537</td>
<td>197</td>
<td>4,599</td>
<td>129</td>
<td>400</td>
<td>50</td>
<td>29%</td>
</tr>
<tr>
<td>Rail Diesel (passenger)</td>
<td>186,000</td>
<td>2,351</td>
<td>91,230</td>
<td>2,553</td>
<td>1,291</td>
<td>265</td>
<td>69.6%</td>
</tr>
<tr>
<td>Rail Electric (passenger)</td>
<td>186,000</td>
<td>3,157</td>
<td></td>
<td></td>
<td></td>
<td>532</td>
<td>69.6%</td>
</tr>
<tr>
<td>Rail Diesel (freight)</td>
<td>186,000</td>
<td>2,385</td>
<td>243,048</td>
<td>6,801</td>
<td>1,721</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rail Electric (freight)</td>
<td>186,000</td>
<td>3,202</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air (domestic)</td>
<td>1,000,000</td>
<td>995,044</td>
<td>28,320</td>
<td>4,867</td>
<td>156</td>
<td>64%</td>
<td></td>
</tr>
<tr>
<td>Air (international)</td>
<td>1,700,000</td>
<td>2,878,972</td>
<td>81,938</td>
<td>10,123</td>
<td>355</td>
<td>78%</td>
<td></td>
</tr>
</tbody>
</table>

* Colours denote source type, as indicated in Table T-2.

3.2.1. Efficiencies of vehicle technologies

Specific assumptions (changing 2000 to 2050/70) were used to estimate the efficiencies (and costs) of vehicles, particularly H₂, fuel cell (FC), hybrid and (battery) electric vehicles, e.g.:

- **H₂ FC car efficiency (%)** = PEM Fuel Cell Efficiency x Electric Engine Efficiency x (1 - Other Efficiency losses)

- **Methanol FC car efficiency (%)** = H₂ FC car efficiency x methanol reformer efficiency x reduced efficiency of FC using H₂ from reformer

- **Improvements for:** hybrid ICE % (road), regenerative braking % (rail);

- **Aircraft efficiency improvement (%)** = Efficiency change of Engine % x Airframe % x operational/ATC² %

² Efficiency improvements due to new Air Traffic Control operations/systems
Table T-4: General efficiency assumptions

<table>
<thead>
<tr>
<th></th>
<th>2000</th>
<th>2010</th>
<th>2020</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PEM Fuel Cell Efficiency</strong></td>
<td>50.2%</td>
<td>54.3%</td>
<td>59.2%</td>
<td>64.0%</td>
<td>64.0%</td>
<td>64.0%</td>
</tr>
<tr>
<td><strong>Electric Engine Efficiency</strong></td>
<td>92%</td>
<td>92%</td>
<td>93%</td>
<td>94%</td>
<td>94.4%</td>
<td>95.0%</td>
</tr>
<tr>
<td><strong>Vehicle System Efficiency</strong></td>
<td>46.0%</td>
<td>50.0%</td>
<td>55.0%</td>
<td>60.0%</td>
<td>60.4%</td>
<td>60.8%</td>
</tr>
<tr>
<td><strong>H₂ FC car efficiency</strong></td>
<td>40.8%</td>
<td>44.4%</td>
<td>48.8%</td>
<td>53.3%</td>
<td>53.6%</td>
<td>54.0%</td>
</tr>
<tr>
<td><strong>Hybrid FCV improvement</strong></td>
<td>10%</td>
<td>11.0%</td>
<td>13.0%</td>
<td>15%</td>
<td>15%</td>
<td>15%</td>
</tr>
<tr>
<td><strong>% Hybrid FCV</strong></td>
<td>0%</td>
<td>0.0%</td>
<td>25.0%</td>
<td>50%</td>
<td>75%</td>
<td>100%</td>
</tr>
<tr>
<td><strong>Average FC vehicle efficiency</strong></td>
<td>40.8%</td>
<td>44.4%</td>
<td>50.7%</td>
<td>58.0%</td>
<td>60.7%</td>
<td>63.5%</td>
</tr>
<tr>
<td><strong>Methanol Reformer Efficiency</strong></td>
<td>70%</td>
<td>75.6%</td>
<td>82.3%</td>
<td>80%</td>
<td>80%</td>
<td>80%</td>
</tr>
<tr>
<td><strong>Efficiency Reduction using H₂ from Methanol Reformer</strong></td>
<td>73%</td>
<td>74.4%</td>
<td>77.2%</td>
<td>80%</td>
<td>85%</td>
<td>90%</td>
</tr>
<tr>
<td><strong>Methanol FCV efficiency</strong></td>
<td>20.9%</td>
<td>25.0%</td>
<td>31.0%</td>
<td>38.4%</td>
<td>36.5%</td>
<td>43.7%</td>
</tr>
<tr>
<td><strong>Hybrid ICE improvement</strong></td>
<td>15.0%</td>
<td>25.0%</td>
<td>34.7%</td>
<td>40.2%</td>
<td>40.2%</td>
<td>40.2%</td>
</tr>
</tbody>
</table>

* Colours denote source type, as indicated in Table T-2.

### 3.2.2. Capital costs

Similarly to the efficiencies dataset, where possible capital cost components were split into several elements, with specific assumptions changing 2000 to 2050/70 for calculations, i.e.:

- **Total Cost** = Powertrain + Energy storage (+ SCR for diesel HGV, Bus, Rail) + Other
  E.g. Total cost for BEV = \([\text{Power (kW) x $/kW electric engine} + \text{[$/MJ (battery) x MJ/km (vehicle efficiency) x vehicle range (km)}] + \text{Other vehicle costs}\)

- **Assume ‘Other cost’ component same across all technologies**

- **H₂ FC vehicle drive system cost ($/kW) =**
  FC cost ($/kW) + other system costs ($/kW)

- **Methanol FC vehicle powertrain cost ($/kW) =**
  H₂ FC drive system cost + methanol reformer cost

- **Other specific assumptions scaled to range/energy storage, power and efficiency:**
  H₂ storage cost ($/MJ), electric engine cost ($/kW), battery cost ($/kWh)
### Table T-5: General capital cost assumptions

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gasoline ICE</strong></td>
<td>$/kW</td>
<td>38</td>
<td>44</td>
<td>49</td>
<td>49</td>
<td>49</td>
<td>49</td>
<td>49</td>
</tr>
<tr>
<td><strong>Diesel ICE</strong></td>
<td>$/kW</td>
<td>62</td>
<td>69</td>
<td>76</td>
<td>76</td>
<td>76</td>
<td>76</td>
<td>76</td>
</tr>
<tr>
<td><strong>Fuel Cell cost</strong></td>
<td>$/kW</td>
<td>3,000</td>
<td>1,800</td>
<td>500</td>
<td>100</td>
<td>85</td>
<td>65</td>
<td>45</td>
</tr>
<tr>
<td><strong>FC systems cost</strong></td>
<td>$/kW</td>
<td>1,000</td>
<td>75</td>
<td>45</td>
<td>43</td>
<td>40</td>
<td>35</td>
<td>25</td>
</tr>
<tr>
<td><strong>FC Drive System</strong></td>
<td>$/kW</td>
<td>4,000</td>
<td>1,875</td>
<td>545</td>
<td>143</td>
<td>125</td>
<td>100</td>
<td>70</td>
</tr>
<tr>
<td><strong>FC Hybrid Drive System</strong></td>
<td>$/kW</td>
<td>4,122</td>
<td>1,926</td>
<td>567</td>
<td>161</td>
<td>142</td>
<td>115</td>
<td>82</td>
</tr>
<tr>
<td><strong>Cost of FC vehicle at assumed hybrid mix</strong></td>
<td>$/kW</td>
<td>4,000</td>
<td>1,880</td>
<td>549</td>
<td>148</td>
<td>132</td>
<td>109</td>
<td>82</td>
</tr>
<tr>
<td><strong>Power of FC needed relative to ICE vehicle</strong></td>
<td>%</td>
<td>110%</td>
<td>107%</td>
<td>105%</td>
<td>102%</td>
<td>100%</td>
<td>98%</td>
<td>92%</td>
</tr>
<tr>
<td><strong>Methanol reformer cost</strong></td>
<td>$/kgH₂</td>
<td>1500</td>
<td>1000</td>
<td>765</td>
<td>500</td>
<td>458</td>
<td>375</td>
<td>225</td>
</tr>
<tr>
<td><strong>H₂ storage cost</strong></td>
<td>$/MJ</td>
<td>12.49</td>
<td>8.33</td>
<td>6.37</td>
<td>4.16</td>
<td>3.82</td>
<td>3.12</td>
<td>1.87</td>
</tr>
<tr>
<td><strong>Electric engine cost</strong></td>
<td>$/kW</td>
<td>25.3</td>
<td>25.3</td>
<td>22.7</td>
<td>21.7</td>
<td>20.7</td>
<td>18.7</td>
<td>16.0</td>
</tr>
<tr>
<td><strong>Hybrid Energy Controller + Other</strong></td>
<td>$/kW</td>
<td>10.9</td>
<td>10.9</td>
<td>10.9</td>
<td>11.0</td>
<td>11.2</td>
<td>19.6</td>
<td>19.6</td>
</tr>
<tr>
<td><strong>Hybrid relative size (power) ICE</strong></td>
<td>%</td>
<td>64%</td>
<td>64%</td>
<td>64%</td>
<td>64%</td>
<td>64%</td>
<td>64%</td>
<td>64%</td>
</tr>
<tr>
<td><strong>Hybrid relative size (power) electric engine</strong></td>
<td>%</td>
<td>56%</td>
<td>56%</td>
<td>56%</td>
<td>56%</td>
<td>56%</td>
<td>56%</td>
<td>56%</td>
</tr>
<tr>
<td><strong>Hybrid ICE Powertrain Cost (not including Battery)</strong></td>
<td>$/kW(Petrol)</td>
<td>51.6</td>
<td>56.2</td>
<td>59.3</td>
<td>58.8</td>
<td>58.4</td>
<td>61.3</td>
<td>59.8</td>
</tr>
<tr>
<td></td>
<td>$/kW(Diesel)</td>
<td>74.4</td>
<td>80.9</td>
<td>86.0</td>
<td>85.5</td>
<td>85.1</td>
<td>88.0</td>
<td>86.6</td>
</tr>
<tr>
<td><strong>BEV/Hybrid battery cost</strong></td>
<td>$/kWh</td>
<td>1,667</td>
<td>693</td>
<td>305</td>
<td>247</td>
<td>235</td>
<td>210</td>
<td>160</td>
</tr>
<tr>
<td></td>
<td>$/kW(hybrid)</td>
<td>122</td>
<td>51</td>
<td>22</td>
<td>18</td>
<td>17</td>
<td>15</td>
<td>12</td>
</tr>
<tr>
<td><strong>Range BEV, km</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Light duty</strong></td>
<td></td>
<td>113</td>
<td>113</td>
<td>150</td>
<td>165</td>
<td>180</td>
<td>210</td>
<td>270</td>
</tr>
<tr>
<td><strong>Bus</strong></td>
<td></td>
<td>200</td>
<td>225</td>
<td>250</td>
<td>275</td>
<td>300</td>
<td>300</td>
<td>300</td>
</tr>
<tr>
<td><strong>Plug-in Hybrid Powertrain Cost (not including Battery)</strong></td>
<td>$/kW(Petrol)</td>
<td>63.3</td>
<td>68.4</td>
<td>71.4</td>
<td>70.8</td>
<td>67.2</td>
<td>71.2</td>
<td>66.4</td>
</tr>
<tr>
<td></td>
<td>$/kW(Diesel)</td>
<td>92.6</td>
<td>100.4</td>
<td>106.1</td>
<td>105.4</td>
<td>104.0</td>
<td>104.3</td>
<td>98.3</td>
</tr>
<tr>
<td><strong>Plug-in hybrid electric vehicle (PHEV)</strong></td>
<td>%BEV km</td>
<td>60%</td>
<td>60%</td>
<td>60%</td>
<td>60%</td>
<td>60%</td>
<td>60%</td>
<td>60%</td>
</tr>
<tr>
<td></td>
<td>Reduced Eff%</td>
<td>10%</td>
<td>10%</td>
<td>10%</td>
<td>10%</td>
<td>5%</td>
<td>5%</td>
<td>5%</td>
</tr>
<tr>
<td><strong>PHEV Battery range, km</strong></td>
<td>Light duty</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
</tbody>
</table>

* Colours denote source type, as indicated in Table T-2.

For baseline assumptions, hydrogen technology costs (fuel cell, H₂ storage and methanol reformer) were up-scaled by 20% to take into account of optimism-bias in forward estimates.
3.2.3. Operation and maintenance costs

In all vehicle technology categories, operation and maintenance (O&M) costs exclude fuel costs. The fuel cost is accounted endogenously by taking into account vehicle efficiency (fuel demand) and cost of delivered fuel (including any infrastructure costs).

As for the efficiencies and capital costs dataset, where possible operational cost components were split into several elements, with specific assumptions changing 2000 to 2050/70, i.e.:

- **Total Cost** = Maintenance + replacement FC and/or fuel storage + Insurance + Tax (+ SCR reductant for HGV, Bus and Rail diesel)

- **Assume insurance cost relative to base gasoline/diesel and capital cost of vehicle;**

- **Replacement Fuel Cells:**
  - None needed for 2Wheels, Cars, LGVs;
  - One replacement for LGVs and HGVs, up to 2015;
  - One replacement for rail vehicles, up to 2020;

- **Replacement Battery:** once in lifetime for battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs) until 2015, then not required from 2020 vintage;

- **Replacement of compressed gas (LPG, CNG) and hydrogen storage tanks:**
  - Once in lifetime of vehicle for road transport;
  - 3 times in lifetime of vehicle for rail and air transport (due to much longer vehicle lifetimes).

- **Reduce maintenance for road vehicles:**
  - Fuel Cell Vehicles: 15% less from 2025, 25% less from 2030
  - BEVs: varies by mode;

3.3. Technology specific data: Car, two-wheelers and LGVs

3.3.1. Motive power

For cars, which were used as a basis for calculations of efficiency in other modes, certain assumptions were also made on changes to motive power requirements, i.e.:

- Estimated reduction in motive power of 0.3% per period (5 years)
Year 2000 motive power for fuel cell (FC) vehicles is assumed to be an average of ICE and battery. 2050 motive power calculated for FC car from IEA vehicle efficiency improvement + assumptions on overall FC car efficiency.

Fuel cell car assumed to have same motive power requirement as ICE by 2020. Potential for the future is up to 15% improvement in efficiency over ICE due to redesign (IEA H2FC, 2005) and it is assumed it reaches this level by 2070. There are also knock-on effects assumed in downsizing fuel-cells/engines correspondingly, as less power is needed for lighter vehicles with same performance.

Battery electric cars are heavier with higher motive power needed – estimated at 20% more in 2000 (on basis of weight of battery of 200kg for 100km range from IEA H2FC, 2005). Improvement is assumed at 1.5% per period due to similar opportunities for redesign as fuel cell vehicles and reduction in battery weight.

3.3.2. Efficiency

Utilising the approaches already outlined for efficiencies, the following major assumptions/references were used in constructing the technology dataset for light duty road vehicles:

- **2Wheelers:**
  - *Gasoline:* IEA-SMP Model (2004) values for OECD Europe were assumed 2000-2050, with efficiencies constant thereafter;
  - *Fuel Cell:* Calculated according to same relative difference as car FC to BEV.

- **Cars:**
  - **2000, 2005:** Calculated on the basis of information from SMMT on average gCO₂/km of new petrol and diesel cars (SMMT, 2005)
  - **2010:** Values were based on information on anticipated improvements from EU WTW study update (2005);
  - **2050:** Values for gasoline, hydrogen ICE and fuel cell cars were based on those identified in IEA Prospects for H₂ and Fuel Cells (2005). Diesel car efficiency is assumed to remain a similar percentage better than gasoline as in 2010 (as discussed at the road transport workshop, see Annex 1). CNG assumed to improve by 16% relative to diesel (ENGVA, 2006) due to efficiency improvements. Other vehicles (LPG, Flex-ethanol) are assumed to improve in line with gasoline ICE equivalents;
  - **BEVs:** 20% improvement is assumed by 2020 and 30% by 2040, due to use of regenerative braking (DfT, 2004). Improvement per period thereafter is assumed to be in line with assumptions on reduction in motive power requirements for electric vehicles and increases in electric drive train efficiency.
3.3.3. **Capital costs**

Utilising the approaches already outlined for capital costs, the following major assumptions /references were used in constructing the technology dataset for light duty road vehicles:

- **Two-wheelers:**
  - **Gasoline:** based on the average price of bikes up to 750cc from RAC (2004);
  - **Electric:** based on assumptions of electric engine cost, battery cost, power and range (only 70 miles/114km for BEV in 2000, rising up to 300km by 2070)
  - **Fuel Cell:** based on assumptions on H₂ storage (same range as gasoline) and Fuel Cell

- **Cars:**
  - **2000, 2010:** Values were based on information from EU WTW study update (2005);
  - **Flex-Ethanol (E85) Cars:** Calculated from Gasoline vehicle cost + $200 (CNN, 2006);
  - **Fuel Cell, Hybrid, BEV vehicles:** Calculated based on previously outlined methodology /assumptions for powertrain, energy storage/range (as for 2-wheelers, etc.);
  - **Plug-in hybrid cars:** summarised in section below.

- **LGVs:** Calculated relative to car technologies and year 2000 costs for gasoline and diesel LGVs from the previous model dataset.

3.3.4. **O&M costs**

Utilising the approaches already outlined for operational costs, the following major assumptions /references were used in constructing the technology dataset for light duty road vehicles:

- **2Wheelers:**
Gasoline: based on average (non-fuel) running costs of bikes up to 750cc from RAC (2004);

Electric: maintenance (67% less) and insurance (50% less) based on information from Vectrix (2006).

Fuel Cell: assume maintenance and insurance similar to electric bikes.

Energy storage for H₂, BEV: Assume additional costs for 1 replacement of storage system (compressed gas tanks, batteries, etc.) in vehicle’s lifetime.

Cars:

Gasoline and diesel vehicles: based on average (non-fuel) running costs of from RAC (2004);

Energy storage for H₂, LPG, CNG, PHEV and BEV: Assume additional costs for 1 replacement of storage system (compressed gas tanks, batteries, etc.) in vehicle’s lifetime (for BEV and PHEV assume no replacement needed from 2020 vintage).

Non-conventional vehicles: Additional insurance costs calculated relative to difference in vehicle capital costs for petrol/diesel, other cost components (except fuel storage) generally same as petrol/diesel. Exceptions are: BEVs – assume 50% lower maintenance costs, and fuel cells – assume 15% less maintenance than gasoline ICE for 2025 vintage and 25% less thereafter;

Road tax: based on information on rates from DVLA (2006).

LGVs:

Gasoline and diesel: based on previous MARKAL dataset (maintenance, insurance);

Other technology costs: Calculated on a similar basis to car technologies;

Road tax: based on information on rates from DVLA (2006).

3.4. Technology specific data: Plug-in Hybrid Electric Vehicles (PHEV)

3.4.1. Efficiency

• Assume a battery range of 50 km.

• Assume cars and LGVs limited to travel up to 60% of annual km on battery electricity charged from national grid (see Figure T-4).
• Assume ratio of electric engine (EE) to internal combustion engine (ICE), also known as the degree of hybridisation (DOH), is 60% (i.e. 60% of maximum power is supplied by EE).

• Assume 10% lower efficiency (due to extra weight) compared to hybrid (when running on petrol/diesel) or BEV (when in battery-only operation mode) in 2000 and 2005 periods, 5% from 2010 onwards. This assumption is made on the basis of lighter battery technologies with higher power delivery (e.g. Lithium-ion) and significant downsizing of the ICE.

![Table](image)

Figure T-4: Summary of PHEV assumptions

### 3.4.2. Capital Cost

• Assume combined EE and ICE peak power needs to be higher than conventional ICE to achieve same actual peak power/performance as conventional ICE. Assume 130% (as for current Prius) for 2000-2015, 125% for 2020-2035 and 120% from 2040.

• Assume cost savings in downsizing petrol/diesel ICE are only a half the % downsizing for petrol engines and a third for diesel engines (higher fixed cost due to more complex high pressure injection system).

• Assume additional cost over hybrid gasoline/diesel equivalent for battery range of 50 km, with saving due to downsizing of ICE. The range assumption is used in combination with vehicle efficiency to calculate the size of battery storage, with the battery cost calculated on basis of assumptions on battery $ per kWh.

• Assume £50 additional cost for battery charging unit.
3.4.3. **O&M Cost**

- Additional insurance costs calculated relative to difference in vehicle capital costs for petrol/diesel, other cost components (except fuel storage) generally same as petrol/diesel.

- Assume additional costs for 1 replacement of battery storage system in vehicle’s lifetime up to 2020 and then no replacements thereafter (on basis of improvements in battery lifetime).

PHEVs technologies were not included in the recent MARKAL runs for the EWP 2007. This is because there is a modelling challenge that is still be developed. If the model chooses to supply electricity for plug-in hybrid vehicles, this will contribute to capacity (kw) demand. We therefore have to specify that demand should not occur during typical peak-hours, as it is likely that vehicles to be charged at off-peak time. Modelling this is quite challenging; and a potential solution may be the use of storage technologies to charge these plug-in vehicles. If the transport demand is only a small share of total electricity demand, then we may also ignore this complex issue. However, it is likely that plug-in hybrid vehicles may make a significant contribution to meeting transport demand.

3.5. **Technology specific data: HGVs and buses**

3.5.1. **Efficiency**

Utilising the approaches already outlined for efficiencies, the following major assumptions /references were used in constructing the technology dataset for heavy duty road vehicles:

- **HGVs:**

  - *Year 2000:* Data for year 2000 diesel is assumed at 37.3 l/100 km (based on previous MARKAL dataset). Other technologies are calculated relative to the assumed efficiency for using corresponding LGV data. [An exception is diesel hybrids, where only 50% of the improvement assumed for cars/LGVs is used, due to smaller proportion of urban km].

  - *2005-2050/70:* efficiencies are assumed to change at the same rate as LGV technology equivalents.

- **Buses:**

  - *Year 2000 diesel:* A value of 11.5 MJ/km (36.2 l/100km) is used – from IEA-SMP (2004) for OECD Europe buses;

  - *Diesel hybrid:* Assumed to be 30% more efficient than diesel in 2000 and 40% from 2005 (Edie, 2005), and then increasing from 2015 at the same amount as for cars/LGVs;

  - *BEV efficiency:* A value of 1 kWh/km (DfT, 2004) is taken for 2000, with changes thereafter assumed to be similar to LGV BEVs;
- *Other technologies:* efficiencies are calculated relative to diesel and HGV/LGV/Car values for equivalents; and similarly for improvements 2000-2050/70;

### 3.5.2. Capital costs

Utilising the approaches already outlined for capital costs, the following major assumptions /references were used in constructing the technology dataset for heavy duty road vehicles:

- **HGVs:**
  - *Year 2000:* Diesel vehicle cost (£48,921) taken from previous MARAL dataset (based on Mercedes data), hybrid and fuel cell technologies calculated relative to or on a similar basis to car equivalent data;
  - *CNG:* 2000/2005 total powertrain cost based on IVECO costs from DfT (2004a) - £17000 greater than diesel. Tank cost calculated relative to car equivalent based on different efficiency and range/tank size of HGVs. Other vehicle costs assumed to be the same as diesel. Powertrain total costs for 2010 onwards calculated relative to diesel and difference in cost for Car petrol ICE and CNG ICE from 2030.
  - Hydrogen ICE powertrain costs assumed to be similar to CNG, with costs for H$_2$ storage calculated based on range and efficiency, as before.
  - *2000-2050/70:* Changes generally calculated relative to assumed cost for year 2000 and car equivalent technologies. Additional costs for SCR systems are assumed for diesel and diesel hybrids from 2010, according to information from AEAT (2005).

- **Buses:**
  - *Diesel:* Assumed capital cost in 2000 is £130,000 total (based on road transport workshop, see Annex 1), with £14,000 for the powertrain only (from DfT, 2004). Additional costs for SCR systems are assumed from 2010 (based on cost data from AEAT, 2004);
  - *Diesel hybrid:* Assumed to be £80,000 more than diesel in 2000 (Edie, 2005), with powertrain costs reducing by 2010 according to DfT (2004). Powertrain costs are then assumed to decrease steadily to be in proportion to HGV equivalents from 2030.
  - *CNG:* Cost differential to diesel is taken at $50,000, $25,000 more (2000, 2010), from WBCSD (2004). Powertrain costs are then assumed to decrease steadily to be in proportion to HGV equivalents by 2060 with no change thereafter.
  - *H$_2$ ICE:* Powertrain costs are calculated relative to CNG and for HGV technology equivalents.
o **Fuel Cells:** Costs are calculated in a similar way to previously using power, range and system cost assumptions.

o **BEV:** Year 2000/5 powertrain cost is taken as £40,000 (Dft, 2004), and calculated to decline at a similar rate to bus CNG powertrains. Battery storage cost is based on reduced range assumptions, increasing from 200km in 2000 to 300km from 2020 onwards.

### 3.5.3. O&M cost

Utilising the approaches already outlined for operating costs, the following major assumptions/references were used in constructing the technology dataset for heavy duty road vehicles:

- **HGVs:**
  - **Diesel:** operating costs for 2000 (tax, maintenance, insurance) taken from previous MARAL dataset (based on Mercedes data). Additional costs (from AEAT, 2005) for SCR system reductant from 2010 (based on fuel consumption);
  - **Hybrid diesel:** Same as for diesel, but with half the SCR reductant costs and insurance cost increased relative to capital cost.
  - **Fuel cell vehicles:** Also require 1 replacement fuel cell in lifetime and maintenance costs decrease compared to diesel by 15% in 2025 and by 25% thereafter, as before.
  - **Other technologies:** Same as diesel, except no SCR system costs, additional cost for 1 replacement of energy storage system and insurance cost increased relative to capital cost.

- **Buses:**
  - **Diesel:** operating costs for 2000 (tax, maintenance, insurance) taken from previous MARAL dataset (based on Mercedes data). Additional costs (from AEAT, 2005) for SCR system reductant from 2010 (based on fuel consumption);
  - **Hybrid diesel:** Same as for diesel, but with half the SCR reductant costs and insurance cost increased relative to capital cost.
  - **Fuel Cell vehicles:** Fuel cell vehicles require 1 replacement fuel cell system in lifetime and maintenance costs decrease compared to diesel by 15% in 2025 and by 25% thereafter, as before.
  - **BEV:** Year 2000 battery replacement at 16p/km (Dft, 2004), and calculated to decline at a similar rate to assumptions on battery costs ($/kWh). After 2010 maintenance costs are assumed to decline to 75% of diesel by 2030 and 60% of diesel by 2070.
3.6. Technology specific data: Rail

The rail vehicle dataset was constructed mainly using information and data from the UIC Rail Diesel Study (UIC RDS, 2006) and a study by Rail Research UK into future power technologies (RRUK-PFG, 2005). The difference between energy use for passenger and freight rail was calculated from previous MARKAL dataset assumptions. Vehicle lifetime was taken to be 40 years, as in the previous dataset, with annual km also remaining the same (186,000 km) in the absence of alternative information.

In the UIC study, cost and efficiency data was available for new DMU and diesel locomotives. Data on the average split of DMU and locomotives in the UK (Railfan, 2005) was used to derive average unit values. It was assumed for modelling purposes that each passenger train unit comprised of 2 rail units and for freight 1 rail unit. For diesel vehicles the average train energy use, capital and operational costs for the model were calculated from these values for 2000. Values of efficiency and cost for 2010 and 2015 diesel rail vehicles were calculated on the basis of industry estimations for vehicles meeting emission limits IIIA and IIIB respectively from UIC RDS (2006).

Year 2000 efficiency for electric and hydrogen fuel cell powered rail vehicles were calculated on the basis of information from RRUK-PFG (2005) on traction efficiency. Values for 2050 for diesel, electric and hydrogen fuel cell rail vehicles were calculated from the projected traction system efficiencies from the RRUK study, and assuming all new passenger rail vehicles utilised regenerative braking (with 15% improvement in efficiency).

Capital costs for electric rail vehicles in 2000 are estimated to be the same as diesel equivalents up to the existing network capacity, plus an additional £500k charge for track electrification where capacity exceeds existing electrification (RRUK-PFG, 2005). For hydrogen rail vehicles capital costs are calculated from the average powertrain power (kW) and the same assumptions on projected fuel cell system and hydrogen storage as used for road transport. 2050 costs were calculated on the basis of additional costs for energy storage for regenerative braking from RRUK-PFG (2005).

Additional costs for SCR reductant (urea) were added to diesel rail vehicles from 2015 in accordance with expectations from UIC RDS (2006). Operating/maintenance costs (excluding fuel) for electric rail vehicles were assumed to have the same differential to diesel (minus any SCR reductant costs) as in previous MARKAL model. It was assumed hydrogen fuel cell vehicles would have similar operating/maintenance costs as electric vehicles (plus a single fuel cell replacement cost for new vehicles up to 2035).

Efficiencies and costs for interim periods (between 2000-2050) were calculated from incremental changes for electric and diesel rail vehicles, taking into account increasing proportions of regenerative braking (for passenger vehicles only), and taking into account changes in hydrogen and fuel cell system costs for H2 fuel cell vehicles.

Where no data was available to suggest changes to capital or maintenance costs, these were assumed to remain unchanged. For hydrogen fuel cell rail vehicles, basic maintenance costs were assumed to be the same as for diesel equivalents in 2020, reducing to the same as

- **Other technologies**: Same as diesel, except no SCR system costs, additional cost for 1 replacement of energy storage system and insurance cost increased relative to capital cost.
electric rail vehicles by 2050. Additional operating costs were assumed for 3 replacements of hydrogen storage systems in the fuel cell vehicle’s 40-year lifetime.

3.7. Technology specific data: Aircraft

The aviation vehicle dataset (split into domestic and international aircraft) was based mainly on various UK reports from DfT and Defra, plus information from IPCC’s 1999 report and on data from IEA H2FC (2005) for hydrogen fuelled aircraft (see references section). An aircraft lifetime of 30 years is assumed (intermediate value in the 25-35 year range in IPCC, 1999). Average annual km of domestic (1 million km) and international (1.7 million km) aircraft were estimated from Civil Aviation Authority (CAA, 2006) statistics on annual km and fleet numbers by aircraft type for 2000, selecting a mix of representative aircraft according to those utilised by DfT (2003) in emission forecasts. Average seating occupancy for domestic (64%) and international (77.9%) aircraft were taken from DfT statistics for 2000.

3.7.1. Efficiency

Fuel consumption for year 2000 domestic and international aircraft was calculated from global figures on fuel usage and km travelled from Defra (2005). Year 2010 efficiency improvements (-18.7%) were based on 10% improvement in engines from IATA (2006) and 5% reduction for minimum airframe improvements and 4.9% for minimum operational/Air Traffic Control (ATC) improvements from ADL (2000). Incremental improvements were calculated to kerosene aircraft in 10 year steps to 2050 with -50% energy use relative to 2000, based on engine, airframe and operational improvements from ADL (2000) and on IPCC (1999).

After 2050, improvements to engine efficiency were assumed at 3% every 5 years. New airframe concepts (such as the Blended Wing-Body) are also introduced for international aircraft in 2020, with reductions in energy use of -10% compared to conventional kerosene in 2020, dropping to -30% by 2050 (maximum potential according to IPCC, 1999). Cryogenic hydrogen fuelled aircraft are introduced from 2020 with efficiencies 27.5% worse than conventional kerosene aircraft (IPCC, 1999), falling to 20% worse by 2040 (IEA H2FC, 2005), with improvements in line with conventional aircraft thereafter.

3.7.2. Capital costs

The seating capacities of domestic (156) and international (355) aircraft were estimated from the mix of representative short and long-haul aircraft utilised by DfT (2003) in emission forecasts. In the absence of other data these seating capacities were used to scale capital costs of conventional kerosene domestic and international aircraft using the formulae and methodology outlined in AVITAS (2005). (AVITAS are a leading provider of aircraft market valuation information). Cryogenic hydrogen planes are assumed to be 25% more expensive than conventional kerosene aircraft (IEA H2FC, 2005) in 2020 and falling to 20% more expensive by 2040 and a further 1% less per 5-year period thereafter. Blended Wing-Body (BWB) concepts are expected to be ultimately cheaper to build according to information on Boeing’s website. In 2020 it is assumed that the new concept will be 10% more expensive than conventional international aircraft, with this differential dropping by 5% in the first two periods (to 2030), 2% in the following two (to 2040) and 1% per period thereafter.
3.7.3. **O&M costs**

Year 2000 operating costs for conventional aircraft were calculated from CAA (2006) financial statistics and annual km for UK airlines for 2000, taking the maintenance costs only. The average aircraft annual km assumptions were used to calculate different values for domestic and international aircraft. Operating costs were assumed to decline at a rate 1% per annum (on recommendation by DfT) between 2000 and 2030, and at a reduced rate of 0.5% per annum from 2030 to 2050 (with no further decreases thereafter). For hydrogen fuelled aircraft, additional costs were added for assumed 3 replacements of the cryogenic hydrogen storage tanks in the aircraft’s lifetime. Operating costs for BWB kerosene aircraft were assumed to be the same as conventional equivalents.

3.8. **Tax and subsidy**

Road transport duty for most of the fuel is included as shown in Table T-6.

Table T-6: Road transport duty by fuel

<table>
<thead>
<tr>
<th>Fuel</th>
<th>£2000/GJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biodiesel</td>
<td>13.6</td>
</tr>
<tr>
<td>CNG</td>
<td>13.6</td>
</tr>
<tr>
<td>Diesel</td>
<td>13.6</td>
</tr>
<tr>
<td>Electricity</td>
<td>14.04</td>
</tr>
<tr>
<td>Ethanol</td>
<td>13.6</td>
</tr>
<tr>
<td>FT-diesel</td>
<td>13.6</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>13.6</td>
</tr>
<tr>
<td>LPG</td>
<td>14.04</td>
</tr>
<tr>
<td>Methanol</td>
<td>13.6</td>
</tr>
<tr>
<td>Petrol</td>
<td>14.04</td>
</tr>
</tbody>
</table>

4. **Calibration**

The base year 2000 is calibrated to the actual final energy consumption of transport sector. Based on the DUKES (2005) the transport sector final energy use in 2000 was 2315 PJ or 55 million toe. It was assumed 6.08% of the aviation fuel is used for domestic aviation (DTI, 2006a) while the rest is for international aviation. For the calibration, the international aviation is excluded. Similarly, fuel consumed in international marine transport is excluded. Due inadequate data on electricity used in rail or other mode of transport, only one-third of the transport sector electricity is accounted in the transport module. Since electricity
accounted only for 1.3% of the total transport sector final energy use it is ignored. Figure T-5 shows the breakdown for actual\(^3\) fuel use based on DUKES (2005) and the calibrated MARKAL fuel.

Figure T-5: Transport sector fuel use in the base year 2000

Table T-7: Transport fleet fuel efficiency and fuel demand in base year 2000

<table>
<thead>
<tr>
<th>Fleet type</th>
<th>Input fuel</th>
<th>Energy use based on NAEI (PJ)</th>
<th>Energy service demand (BVkm)</th>
<th>Vehicle Efficiency based NAEI (MJ/km)</th>
<th>Adjusted vehicle efficiency for MARKAL (GJ/km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buses</td>
<td>Diesel</td>
<td>51</td>
<td>5.337</td>
<td>9.0</td>
<td>9.48</td>
</tr>
<tr>
<td>Cars</td>
<td>Diesel</td>
<td>134</td>
<td>50.3</td>
<td>2.53</td>
<td>2.66</td>
</tr>
<tr>
<td>Cars</td>
<td>Petrol</td>
<td>951</td>
<td>339.3</td>
<td>2.66</td>
<td>2.80</td>
</tr>
<tr>
<td>HGV</td>
<td>Diesel</td>
<td>371</td>
<td>29.25</td>
<td>12.04</td>
<td>12.68</td>
</tr>
<tr>
<td>LGV</td>
<td>Diesel</td>
<td>157</td>
<td>42.37</td>
<td>3.52</td>
<td>3.71</td>
</tr>
<tr>
<td>LGV</td>
<td>Petrol</td>
<td>42</td>
<td>11.45</td>
<td>3.50</td>
<td>3.69</td>
</tr>
<tr>
<td>2-wheeler</td>
<td>Petrol</td>
<td>6</td>
<td>4.66</td>
<td>1.26</td>
<td>1.33</td>
</tr>
<tr>
<td>Aviation (Domestic)</td>
<td>Aviation fuel</td>
<td>27</td>
<td>0.0999</td>
<td>252.19</td>
<td>265.41</td>
</tr>
<tr>
<td>Rail passenger</td>
<td>Diesel</td>
<td>20</td>
<td>1.19</td>
<td>15.85</td>
<td>16.69</td>
</tr>
<tr>
<td>Rail freight</td>
<td>Diesel</td>
<td>13</td>
<td>0.14</td>
<td>86.90</td>
<td>91.51</td>
</tr>
</tbody>
</table>

\(^3\) Fuel consumption in tonnes were converted using net calorific values from Table A.3 of DUKES (2006)
Based on the reverse engineering technique, the efficiency of individual category vehicles fleet is calculated to ensure 2000 totals are met. Vehicle energy efficiency (GJ/km) is taken from National Atmospheric Emission Inventory (NAEI) statistics (which are based originally on inputs from DfT). Based actual transport sector fuel use and vehicle efficiency the energy service demands are calculated. However, the vehicle efficiencies are slightly adjusted to balance the 2000 actual final energy in DUKES (2005). Figure T-6 shows the final energy use and energy service demand for various transport fleets.

Figure T-6: Transport sector fuel use and energy service demand by fleet type in 2000

4.1. Constraints

The transport sector has a number of constraints imposed to ensure that our understanding of sector structure/energy consumption is properly accounted for.

- Limitations on certain fuel blends e.g. bio-diesel in cars, co-firing in power plant
- Policy implementation e.g. Renewable Transport Fuel Obligation (RTFO)
5. Uncertainties

There are a number of areas of uncertainty with regards to the data used, and assumptions made. In addition, there are some limitations with how well the sector can be modeled. All are subject to review as the model continues to be developed over time. In this section, these are briefly summarized.

- **Future technologies** – much of the ability of the road transport sector to decarbonise is dependent on the introduction of new types of technologies e.g. fuel cells, plug-in hybrids, flex-ethanol technology. Much of the cost / performance data - out to 2050 – is subject to significant uncertainty.

- **Fleet switching** – for some vehicles, rapid take-up is seen over short time periods. In reality, the switching of the fleet might take considerably longer. Modelling techniques are being considered to slow the penetration of specific vehicle types in future time periods.

- **Electricity use in transport sector** – as mentioned earlier in this documentation, consideration is being given to how electricity demand can be modelled to ensure that diurnal variation can be accounted for – that might affect peak demand.

- **Consumer behaviour** – as a cost-optimisation model, choices are made on the basis of cost. However, *real-world* behaviour might suggest choice on the basis of a range of different factors e.g. performance, safety, size etc; the model does not pick such factors up.

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## Appendix T-I: Road Transport Stakeholder Workshop

Date: 6\textsuperscript{th} March 2006, DfT, London

### Agenda & Minutes

<table>
<thead>
<tr>
<th>Time</th>
<th>Topic</th>
<th>Who?</th>
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<tbody>
<tr>
<td>13.30</td>
<td>Welcome and introductions</td>
<td>Nikolas Hill (AEAT)</td>
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<td>13.40</td>
<td>Summary of the project work and the MARKAL model</td>
<td>Neil Strachan (PSI)</td>
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<tr>
<td>13.50</td>
<td><strong>Presentation on data and assumptions for vehicle efficiency (and CO\textsubscript{2} emissions):</strong></td>
<td>Nikolas Hill (AEAT)</td>
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<td>• 2-Wheelers</td>
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<td>14.00</td>
<td>Open discussion of data and assumptions for efficiency</td>
<td>Everybody</td>
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<td>14.45</td>
<td>Break for Tea/Coffee</td>
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<td>15.00</td>
<td><strong>Presentation on data and assumptions for vehicle capital and operational costs:</strong></td>
<td>Nikolas Hill (AEAT)</td>
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<td>15.15</td>
<td>Open discussion of data and assumptions for costs</td>
<td>Everybody</td>
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<tr>
<td>16.15</td>
<td>Summary and closing comments</td>
<td>Heather Haydock / Nikolas Hill (AEAT)</td>
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<td>16.30</td>
<td>CLOSE</td>
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### Attendees:

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Background & Agenda

This workshop aimed to get stakeholder input to the data and assumptions used in the transport module of the updated Markal model. Simplified data tables were circulated to participants a few days before the meeting. Neil Strachan opened the workshop with an introduction to Markal and to the current PSI/FES project. Nikolas Hill then introduced our preliminary assumptions for vehicle efficiency, followed by a discussion. After a short break, Nikolas Hill introduced the preliminary cost assumptions and these were discussed.

Neil Strachan’s introduction prompted a number of questions, including how accurate Markal has proved historically in forecasting, whether the model can take account of oil company views on future fuels, whether and how the model deals with barriers to the introduction of new technologies.

See Nikolas Hill overheads for current data/assumptions, these will be circulated to stakeholders and with comments to be received within 2 weeks.

Data and assumptions on vehicle efficiency

Stakeholder comments on efficiency assumptions:

- Suggested picking up on USDOE modelling work, including Argonne.
- Vans could develop quite differently from cars, e.g. hybrids coming in more quickly. LowCVP vans working group doing relevant work but results will not be available until the summer.
- Hybrid assumptions (% improvement over equivalent gasoline/diesel) – Hybrids work much better in cities, giving up to 50% improvement.
- Scaling factor from drive cycle efficiency to on road efficiency – agreed we need one; no additional suggestions for sources of this.
- Future gasoline engines may be close to the efficiency of diesels and changes in efficiency of gasoline and diesel are likely to track each other.
- BMW – believe they can get up to 50% thermal efficiency from hydrogen in ICE (carnot limitation is 57%). This could be a serious challenge to the fuel cell. Lots of views that fuel cells will never make it.
- Value of exercise is to explore possibilities not predict the future; useful to know where stakeholders agree and where they don’t.
Data and assumptions on capital costs

- Shorter ranges assumed for BEV – is this reasonable? For 3.5t vehicle 60 miles is about the limit for a BE van.

- Might be worth adding in plug-in hybrids to the model, i.e. hybrids that have the option of recharging.

- The lack of end-of-life costs is a limitation to the model. When ELV Directive stipulates 95% by weight and hybrid penetrate further then there will be a cost associated with end-of-life disposal of costs. We were asked to look further into this and in turn requested any relevant data.

- General agreement with $200 premium for flexi-fuel (E85 or petrol) vehicle.

- In future a higher proportion of cars will be made in China so they will be cheaper. But resources are running out, e.g. availability of platinum will reduce in time.

- DTI would like to see different cost assumptions for different future scenarios.

- Emissions control systems may be very much more expensive in future for diesels, but cost reductions will come in through manufacturing improvements. So perhaps little change in conventionally fuelled car costs to 2050 is reasonable.

- Fuel cell vehicle capital costs look low – needs checking. This will be a key sensitivity.

- Might be useful to look at cost data from the supplier base (Ian Massey will look for sources).

- Bus costs and ranges were questioned. Nigel Base and David Joffe offered to provide better data, e.g. cost of diesel bus is about £130k (not £200k which is more typical of a luxury coach). Rob Sullivan asked for the reference for the 2004 DfT study. 400km is the biggest range you’d need for an urban bus.

- Bus power requirement should be lower than HGV power requirement, not higher.

Data and assumptions on operating costs

- Most company vehicles are self insured because of the high excesses payable.

- Resale ability and value are important, but can’t be modelled easily in Markal.