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Road transport sector modelling

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July 2011

Prepared for the Department of the Treasury

Report No: EP114249

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EXECUTIVE SUMMARY

To support Treasury's role in supplying quantitative modelling input to the Multi-Party Climate Change Committee, CSIRO has been commissioned by the Commonwealth Department of Treasury to conduct economic modelling of the impact of alternative carbon price scenarios on the road transport sector in Australia out to 2050.

CSIRO's modelling is one part of an integrated package of modelling that has been coordinated by Treasury. The outputs of this whole modelling package are summarised in *Strong Growth, Low Pollution: Modelling a Carbon Price*. The purpose of the *Road transport sector modelling* report is to provide additional detail on the road sector model assumptions and results.

The modelling examined four key scenarios:

- **Medium global action:** Reference case scenario that assumes the rest of the world pursues an emission reduction trajectory to 550 parts per million (ppm) with no formal emissions reduction target for Australia.

- **Ambitious global action:** Reference case scenario that assumes the rest of the world pursues an emissions reduction trajectory to 450 ppm with no formal emissions reduction target for Australia.

- **Core policy:** A carbon pricing scheme is adopted, assumed to commence on 1 July 2012, with a national emissions target of 5 percent below 2000 levels by 2020 and 80 percent below 2000 levels by 2050. The starting carbon price is $18.50/t in 2009-10 dollars ($20 nominal) rising 5% real for 3 years then floating. The fuel tax treatment as outlined in Section 3.1 is implemented. Fuel used in private passenger and light commercial vehicles and the use of natural gas or liquefied petroleum gas (LPG) is excluded indefinitely from a carbon price. The core policy scenario does not reflect the final policy package as agreed by the MPCCC.

- **High-price:** A carbon pricing scheme is adopted, assumed to commence on 1 July 2012, with a national emissions target of 25 percent below 2000 levels by 2020 and 80 percent below 2000 levels by 2050. The starting carbon price is $27.50/t in 2009-10 dollars ($30 nominal) rising 5% real for 3 years then floating. Fuel tax offsets as outlined in Section 3.1 are implemented.

Five additional sensitivity cases were also modelled. They were:

- **Low-price sensitivity:** A carbon pricing scheme is adopted, assumed to commence on 1 July 2012, with a national emissions target of 5 percent below 2000 levels by 2020 and 80 percent below 2000 levels by 2050. The starting carbon price is $9/t in 2009-10 dollars ($10 nominal) rising 5% real for 10 years then floating. Fuel tax offsets as outlined in Section 3.1 are implemented.

- **Medium-price sensitivity:** A carbon pricing scheme is adopted with the same national target as the Core policy scenario. Fuel tax offsets as outlined in Section 3.1 are implemented. However, they are not extended for private passenger and light commercial vehicles or for use of natural gas and liquefied petroleum gas.

- **Unshielded high-price sensitivity:** A carbon pricing scheme is adopted with the same national target as the High-price scenario. However, it is assumed that the carbon price is floating from the commencement of the scheme and fuel tax offsets are not available.

- **High oil price sensitivity on Medium global action and Medium-price sensitivity (High-oil/Medium global action and High oil/medium-price):** The 550ppm reference and Medium-price scenarios are modelled with the same assumptions except a higher oil price is assumed.

- **Low oil price sensitivity on Medium global action and Medium-price sensitivity (Low-oil/Medium global action and Low oil/medium-price):** The 550ppm reference and Medium-price scenarios are modelled with the same assumptions except a lower oil price is assumed.

Figure 0-1: Road transport greenhouse gas emissions by scenario shows road transport greenhouse gas (GHG) emissions by scenario or sensitivity case. Some general findings in regard to GHG emissions from the scenario analysis are:

- Emissions increase over time under the Medium global action and Ambitious global action scenarios to around 94 $MtCO_2e$ by 2050.

- Road transport sector emissions are projected to decrease by between 25 to 70 percent by 2050 when a carbon price is imposed, relative to a no carbon price scenario. This response is greater than was observed in *Australia's Low Pollution Future* reflecting lower assumed costs and greater volumes of alternative fuels and vehicles (based on new research) and higher oil price assumptions.

- Higher oil prices reinforce incentives for greenhouse gas abatement in the road transport sector by ensuring that low emission alternative fuels are closer to their competitive range compared to existing fuels.

- The High-price scenario leads to a 70 percent reduction in greenhouse gas emissions by 2050, relative to a no carbon price scenario. If the High-price scenario is modelled with no fuel tax offset it provides additional road transport sector abatement of 0.3 to 1.7 $MtCO_2e$ per annum over the projection period.

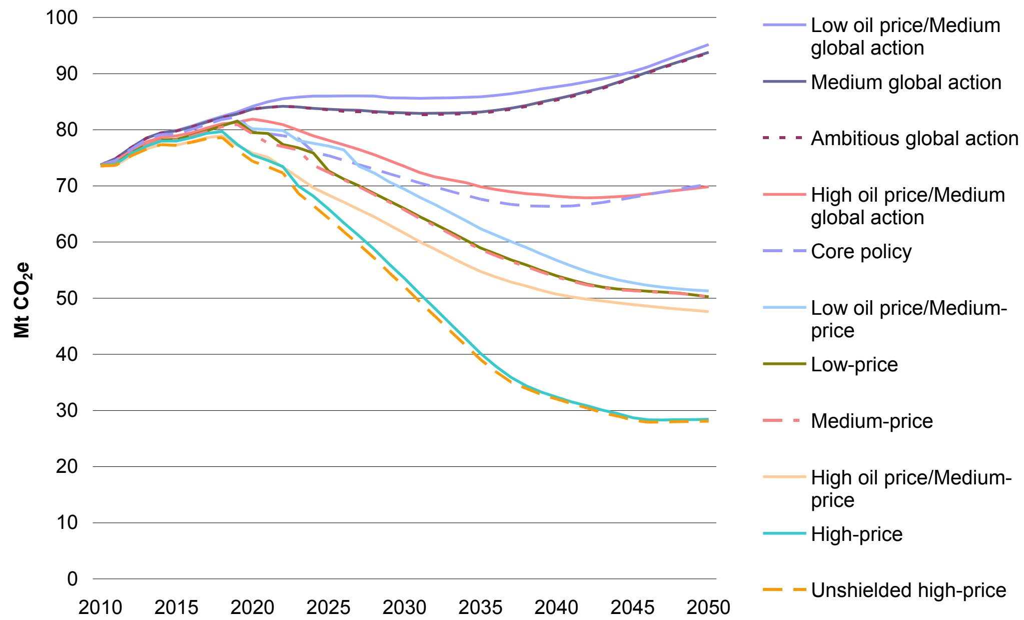

Figure 0-1: Road transport greenhouse gas emissions by scenario

In regard to the uptake of alternative fuels, Figure 0-2 shows that in the short- to medium-term, higher carbon prices lead to greater uptake of biofuels (ethanol and biodiesel). Biofuels consumption accelerates further in the long term together with electricity and natural gas (mostly as LNG in trucks or converted to diesel).

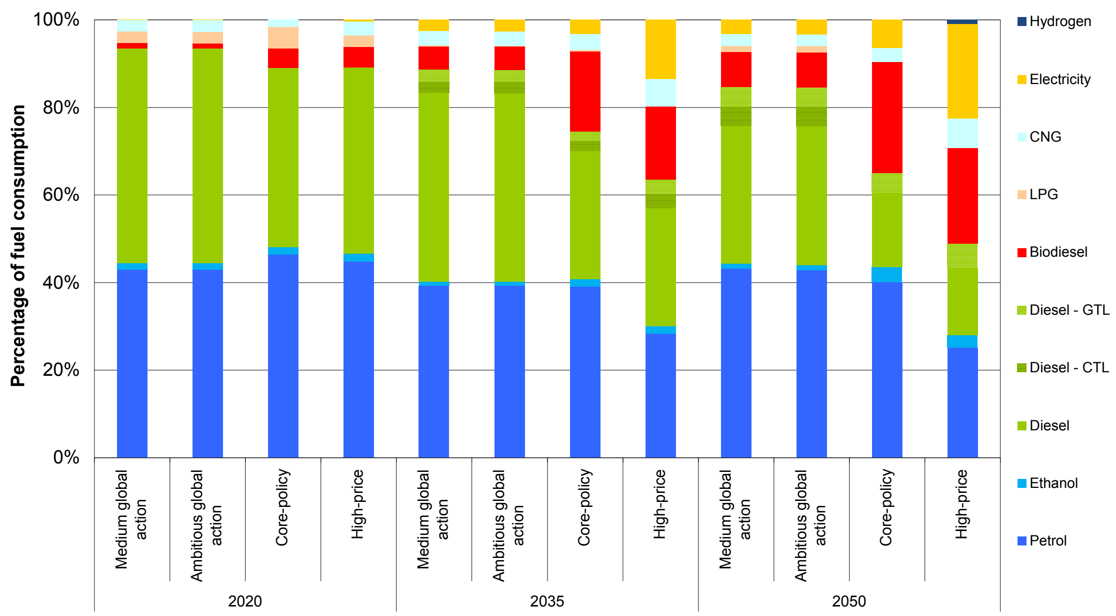

Figure 0-2: Road transport fuel consumption by scenario

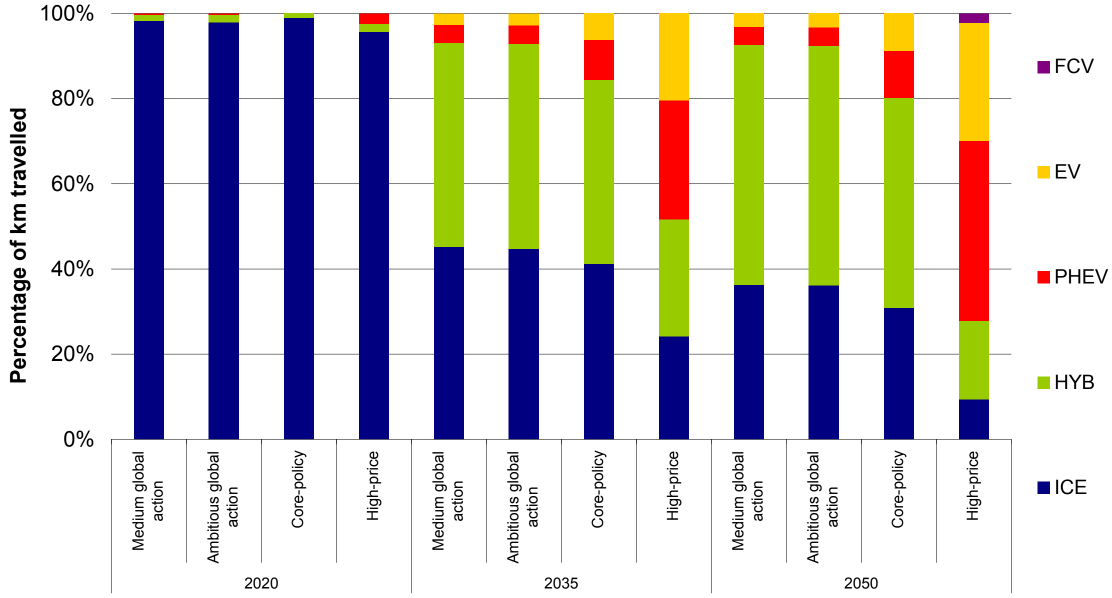

Figure 0-3: Road transport vehicle mix by scenario

In regard to the uptake of alternative vehicles, Figure 0-3 shows that in the short-term, higher carbon prices lead to greater uptake of mild hybrid (HYB) and plug-in hybrid vehicles (PHEV). Fully electric vehicles (EV) are also taken up from just after 2020. In the long-term, three more efficient engine types dominate the vehicle fleet with some uptake of fuel cell vehicles (FCV) towards the end of the projection period.

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ACRONYMS AND ABBREVIATIONS

ABARE	Australian Bureau of Agriculture and Resource Economics
ABARES	Australian Bureau of Agriculture and Resource Economics and Sciences
ABS	Australian Bureau of Statistics
ALPF	Australia's Low Pollution Future
bbl	Barrel
BITRE	Bureau of Infrastructure, Transport and Regional Economics
CCS	Carbon Capture and Storage
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
CNG	Compressed Natural Gas
CPRS	Carbon Pollution Reduction Scheme
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CTL	Coal-to-liquids
ESM	Energy Sector Model
EV	Electric vehicle
FCV	Fuel cell vehicle
FT	Fischer-Tropsch
g	grams
GHG	Greenhouse gas
GJ	Gigajoule
GL	Gigalitre
GTL	Gas-to-liquids
HV	Heavy vehicle
ICE	Internal combustion engine
IEA	International Energy Agency
km	kilometres
kWh	Kilowatt hour
LCV	Light commercial vehicle
LNG	Liquefied natural gas
LPG	Liquefied petroleum gas
MJ	Megajoule
Mt	Megatonnes
NA	Not applicable
NSW	New South Wales
PAS	Passenger vehicle
PHEV	Plug-in hybrid electric vehicle
PJ	Petajoule
ppm	Parts per million
t	tonne
TWh	Terawatt hour
VKT	Vehicle kilometres travelled

ACKNOWLEDGEMENTS

We acknowledge Brendan McKenna, Xavier Rimmer, Michael McNamara and Ben Dolman of the Department of Treasury for providing valuable input to the modelling. We thank Thomas Brinsmead and Jim Smitham of CSIRO for internal review of this report. The final results presented herein remain the responsibility of the authors.

1. INTRODUCTION

To support Treasury's role in supplying quantitative modelling input to the Multi-Party Climate Change Committee, CSIRO has been commissioned by the Commonwealth Department of Treasury to conduct economic modelling of the impact of alternative carbon price scenarios on the road transport sector in Australia out to 2050.

CSIRO's modelling is one part of an integrated package of modelling that has been coordinated by Treasury. The outputs of this modelling package are summarised in *Strong Growth, Low Pollution: Modelling a Carbon Price*. The purpose of the *Road transport sector modelling* report is to provide additional detail on the road sector model assumptions and results.

The modelling examines four main scenarios — two reference scenarios and two scenarios which investigate the impact of alternative carbon price levels on the deployment of alternative road fuels and vehicles. In addition, five sensitivity cases model the impact of a lower carbon price, greater fuel coverage and high and low oil prices. This report documents the main findings of the modelling for the reference and sensitivity scenarios.

This report is structured as follows. Section 2 provides an overview of the modelling framework used in the scenario analysis. Section 3 defines the scenario and sensitivity case assumptions preceding the discussion of scenario results in Section 4. Section 5 compares and contrasts the modelling results with *Australia's Low Pollution Future*.

2. MODELLING APPROACH

2.1 Energy Sector Model (ESM)

ESM is an Australian energy sector model co-developed by the CSIRO and the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) in 2006. Since that time CSIRO has significantly modified and expanded ESM.

ESM is a partial equilibrium (‗bottom-up') model of the electricity and transport sectors. The model has a robust economic decision making framework that incorporates the cost of alternative fuels and vehicles as well as detailed fuel and vehicle technical performance characterisation such as fuel efficiencies and emission factors by transport mode, vehicle type, engine type and age. In this study, only the road transport module of ESM was used.

ESM has been widely applied in scenario analysis of transport energy futures including: alternative emission targets (e.g. CSIRO, 2008; Graham et al., 2008; Reedman and Graham, 2009), alternative carbon price regimes (e.g. BITRE and CSIRO, 2008; CSIRO and ABARE, 2006; Commonwealth of Australia, 2008) and high oil price scenarios (Graham and Reedman, 2010).

ESM includes a wide range of assumptions about the cost fuel efficiencies, and emission factors of alternative fuels and vehicles. Further details of the structure of ESM and the key data inputs are outlined in Appendix A.

2.2 Integration of ESM with the Treasury model suite

ESM has been applied as part of an integrated modelling suite. The integrated modelling suite includes models of the global and national economy as well as models of individual sectors such as road transport and electricity. Sector models are included within the modelling suite to provide more detail about how particular sectors of interest respond to a carbon price or other important scenario assumptions and drivers.

The models are typically integrated by exchanging data. Data outputs from one model are used as data inputs to another model. Data is then exchanged in the reverse direction. Full consistency can never be entirely achieved because the models represent common parts of the economy in different levels of detail. However, a reasonable level of consistency is achieved through aggregation and other means. Working through any differences identified often leads to improvements in all models.

The process of achieving reasonable consistency was carried out for each scenario. However, for expediency, the sensitivity cases were only run once-through.

The key items of data inputs to ESM road transport sector modelling are:

- The level of transport activity each year by public and private passenger and freight transport categories by State
- The carbon prices each year

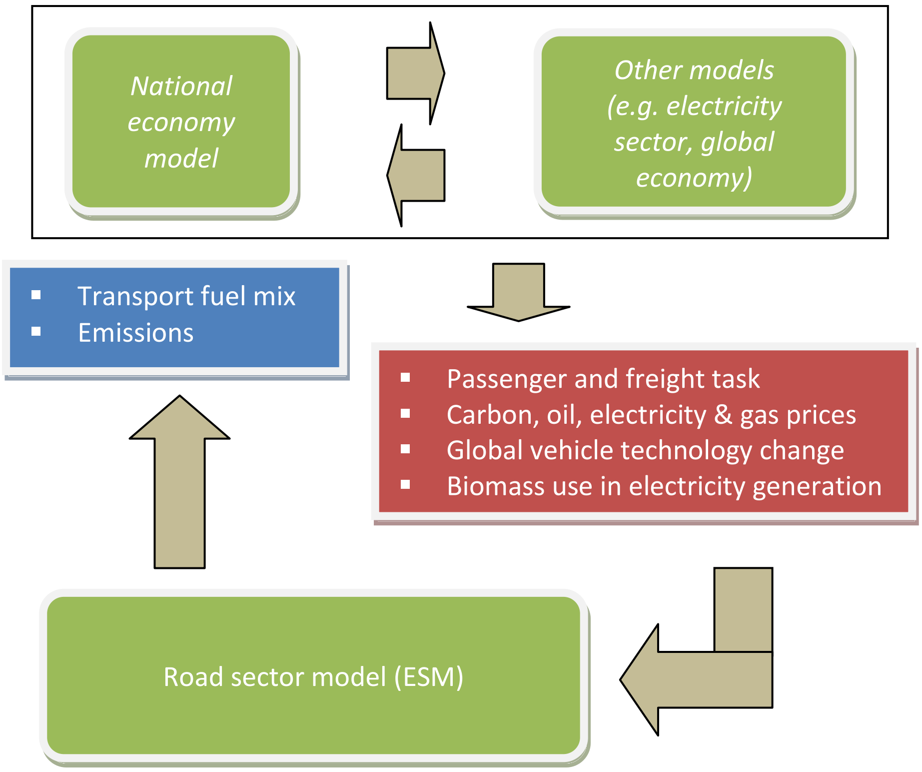
- The oil and natural gas prices each year
- The retail electricity price each year by State
- An index of global vehicle technological change.

For consistency, the level of biomass use projected to occur in electricity generation in the modelling suite was checked to ensure it did not limit the volume of biomass available for conversion to road fuels.

The outputs that ESM provides back into the modelling suite are

- Road sector fuel consumption each year by fuel, vehicle type and State
- Road sector emissions by fuel, vehicle type and State.

Figure 2-1 shows the inputs and outputs of the modelling.



Key: Blue = Data output from ESM; Green = Modelling frameworks; Red = Inputs to ESM.

Figure 2-1: Inputs into and outputs from the modelling frameworks

3. SCENARIO DEFINITION

- **Medium global action:** Reference case scenario that assumes the rest of the world pursues an emissions reduction trajectory to 550 parts per million (ppm) with no formal emissions reduction target for Australia.

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3.1 Fuel tax offset assumptions

Under a carbon price, almost all types of road fuels will increase in price to reflect the pricing of the carbon dioxide emitted in combustion. The exception is ethanol and biodiesel, whose combustion emissions will not be priced. This follows the convention that the combustion emissions from biofuels are equal to the amount of carbon dioxide reabsorbed when the biomass feedstocks are re-grown and therefore over their life cycle, neglecting emissions during transport and processing, do not contribute additional carbon dioxide to the atmosphere.

When the fuel tax offset scheme is assumed to be in place, fuel excise is reduced by [Carbon Price / ($10/t)] * 2.455 cents per litre (nominal) for petrol and diesel to reflect the prevailing carbon price. For some scenarios the offset remains in place indefinitely, for others the level of excise is reduced in each of the first one to three years of the scheme. In such cases, this reduction in excise is assumed to be permanent, but any incremental increase in the carbon tax in the fourth year and future years will flow through to fuel users.

The arrangements also includes a fuel credit for businesses operating a heavy road vehicle (weighing 4.5 tonnes or more), who would not benefit from the cut in excise because they would normally be able to claim any excise paid as company tax already paid at the end of the year (i.e. as a fuel tax credit). The credit is also available for LPG, CNG and LNG.

The fuel credit is assumed to be applied at the rate:

- [Carbon Price / ($10/t)] * 2.455 cents per litre for petrol or diesel for heavy on-road vehicles for the first year of the scheme
- 0.67 * [Carbon Price / ($10/t)] * 2.455 cents per litre for LPG for the first three years of the scheme based on the prevailing carbon price
- 0.78 * [Carbon Price / ($10/t)] * 2.455 cents per cubic metre for compressed natural gas for the first year of the scheme
- 0.5 * [Carbon Price / ($10/t)] * 2.455 cents per litre for LNG for the first year of the scheme.

This heavy vehicle fuel credit assistance is assumed to be temporary in all scenarios, so that in the second year and future years heavy vehicle operators face higher fuel costs to reflect the full amount of the carbon tax.

3.2 Other key scenario assumptions

Carbon price assumptions were provided by the Treasury for the two carbon pricing scenarios and for the low price sensitivity case. The carbon price for the core policy scenario commences from July 2012 at \$18.50/tCO_2e (2009-10 dollars), and then jumps in FY 2016 from \$20/t CO_2e to \$25/t CO_2e, and grows at 5% real per annum thereafter. Under the high price scenario the initial carbon price is \$27.50/t CO_2e (2009-10 dollars), commencing in July 2012. As with the core policy scenario the price steps up in FY 2016, although to a much higher level (from \$30.50/t CO_2e to \$52/t CO_2e) and it continues to grow at 5% real per annum thereafter. The carbon price for the low price sensitivity case also commences from July 2012 at \$9/t CO_2e (2009-10 dollars). However, the step jump in price is deferred to FY 2023 when it jumps from \$14/t CO_2e to around \$35.50/t CO_2e, where the latter price is identical to that of the core policy scenario in FY 2023. The carbon price trajectory for the low price sensitivity case then tracks that of the core policy scenario having a real growth rate of 5% per annum thereafter.

The prices of oil and gas associated with each scenario or sensitivity case are shown in the following figures.

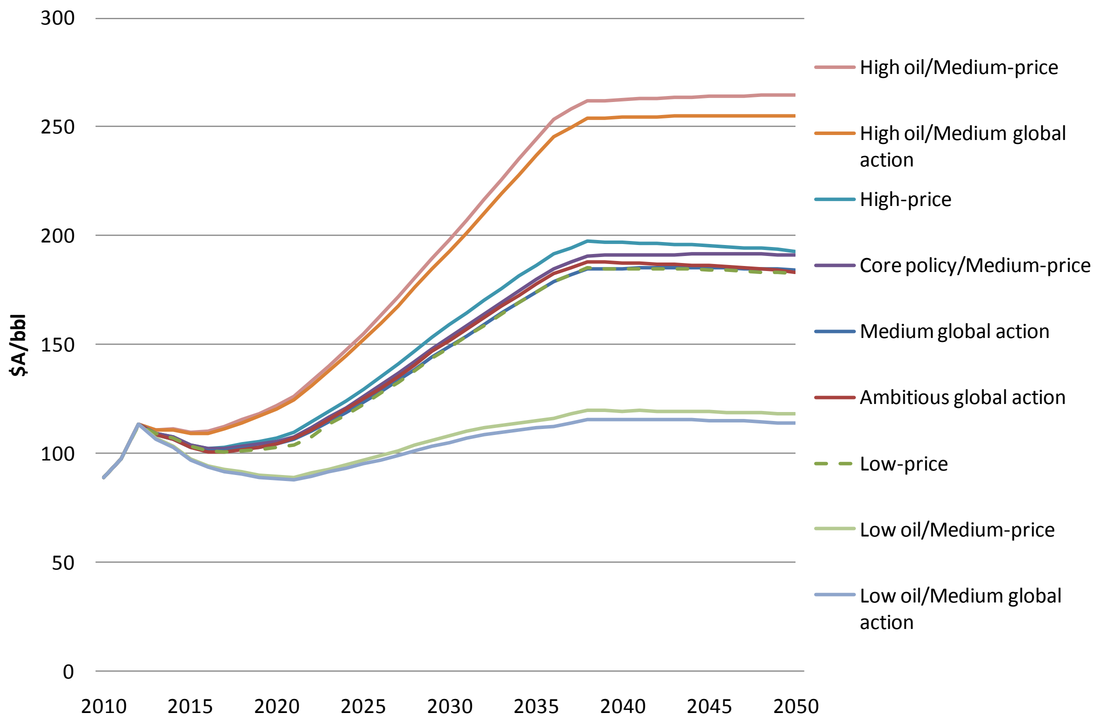

Figure 3-1: Oil price assumption for each scenario or sensitivity case

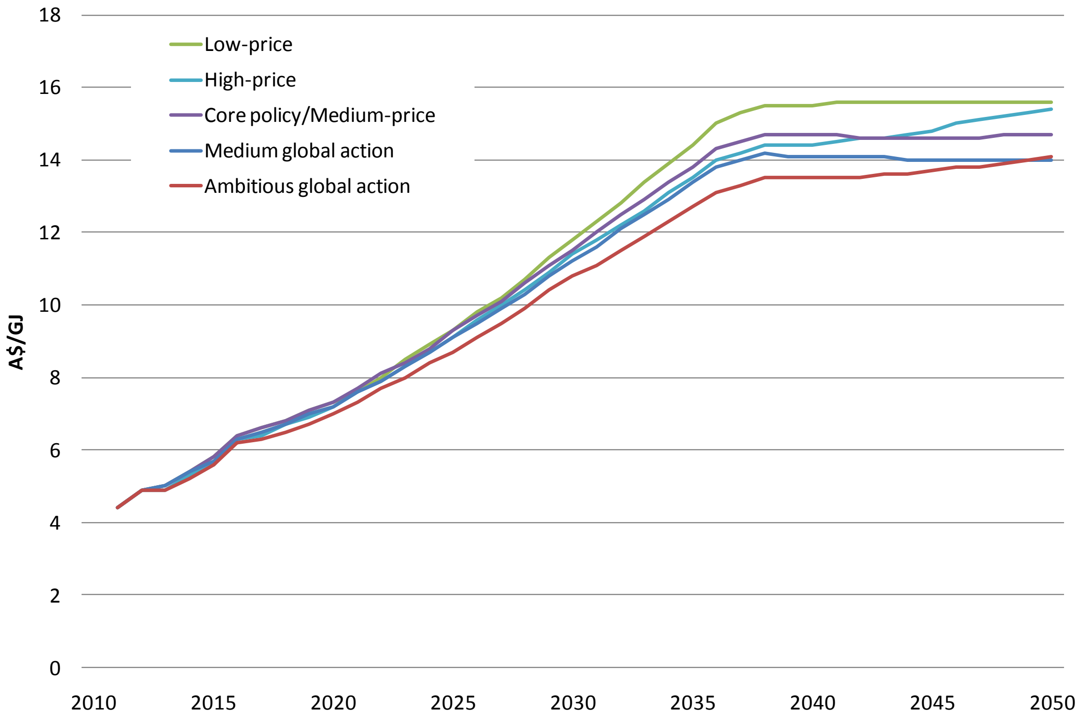

Figure 3-2: Wholesale natural gas price for each scenario

4. SCENARIO AND SENSITIVITY RESULTS

This section reports the modelling results for each scenario and sensitivity case.

4.1 Medium global action scenario

The Medium global action scenario assumes continuation of current transport policy settings moderately increasing oil prices to 2035 which flatten out thereafter reflecting abatement activities in the rest of the world (see Figure 3-2). By 2050 the oil price is $A184/bbl (2009-10 dollars).

Figure 4-1 shows the road transport demand by mode and road vehicle type in the reference scenario growing to 462 billion kilometres by 2050. It should be noted that the share of kilometres travelled by small passenger (PAS) and light commercial vehicle (LCV) modes is increased over the projection period, based on the observation that vehicle purchase decisions tend toward smaller vehicles as oil prices rise. This assumption applies across all scenarios.

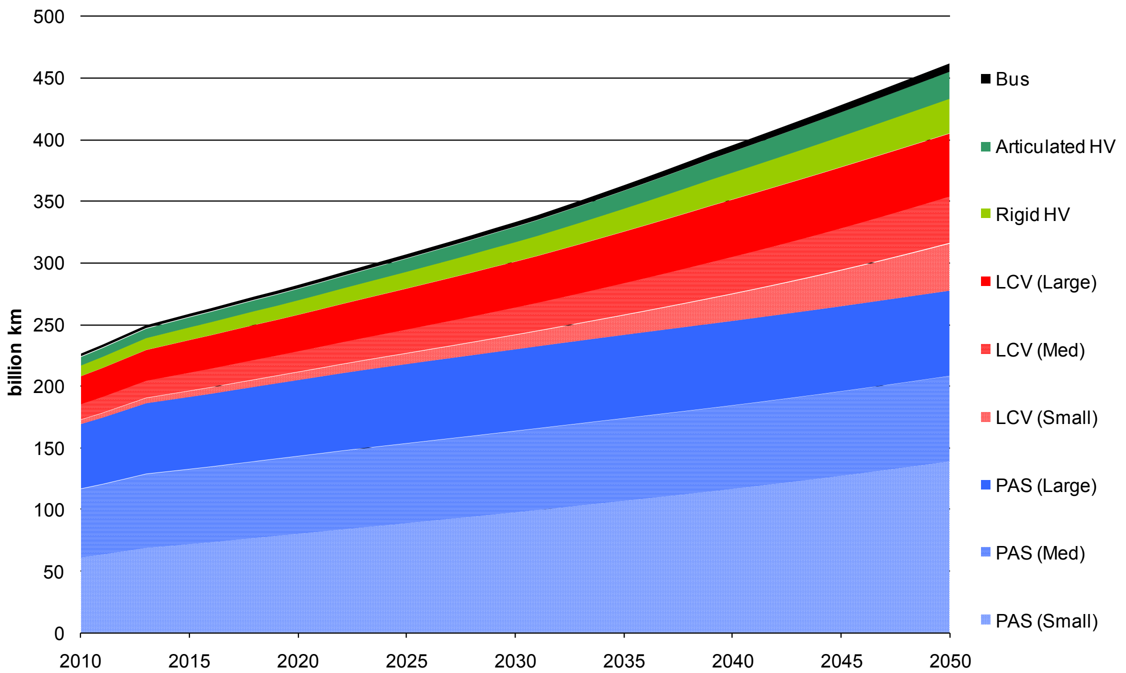

Figure 4-1: Transport demand by mode and road vehicle type, Medium global action scenario

Figure 4-2 and Figure 4-3 shows that despite the steady growth in demand for vehicle kilometres travelled (VKT), the amount of energy consumed by the road transport sector increases more slowly during the period from 2015 to 2035. This reflects the adoption of both smaller vehicles and more efficient engine technologies during this period.

Diesel becomes more significant as a car fuel in the next two decades. The initial increase in the uptake of diesel vehicles reflects their improved economics. The additional cost of purchasing a diesel vehicle is to some extent offset by savings from improvements in fuel efficiency together with the rise in oil prices. The increase in diesel engine efficiency is attributed primarily to the availability of European-designed diesel engines which up until recently were not compatible with our diesel fuel as set by the national standards.

From around 2025, petrol consumption recovers diesel market share as mild hybrids become a cheaper and comparatively efficient vehicle relative to diesel internal combustion engine (ICE)-only (see Figure 4-4). Ethanol and biodiesel blends increase their share significantly reflecting both their cost competitiveness against the petroleum alternatives and the support of the NSW ethanol mandate (see default policy assumptions in Appendix A).

GTL and CTL diesel fuels also become cost-effective and hold a moderate share of the market by 2050. Compressed natural gas (CNG) (mostly in the form of liquefied natural gas (LNG)-fuelled trucks) and electricity both emerge as significant fuels from a near zero share at present. The total use of electricity in road transport by 2050 is 48 petajoules (PJ) which is equivalent to around 13 terawatt hours (TWh).

Liquefied petroleum gas (LPG) use declines significantly by around 2030 only recovering slightly by 2050. This reflects competition from hybrid petrol vehicles in the light commercial vehicle market and our assumption that LPG prices moves in accord with international oil prices. This assumption is largely supported by the historical data (see for example ACCC (2009), page 141 and 146). Under the modelling assumptions, as the price of hybrids and LPG vehicles converge, it is hybrid vehicles that eventually have the lower fuel costs.

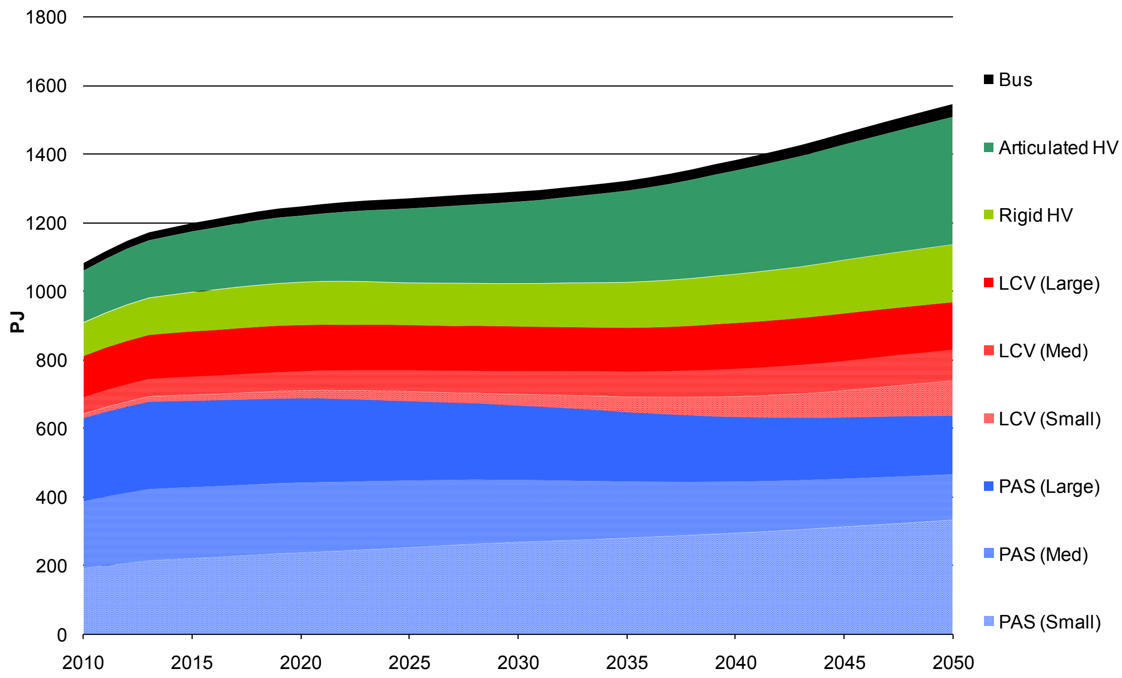

Figure 4-2: Road transport fuel consumption by mode, Medium global action scenario

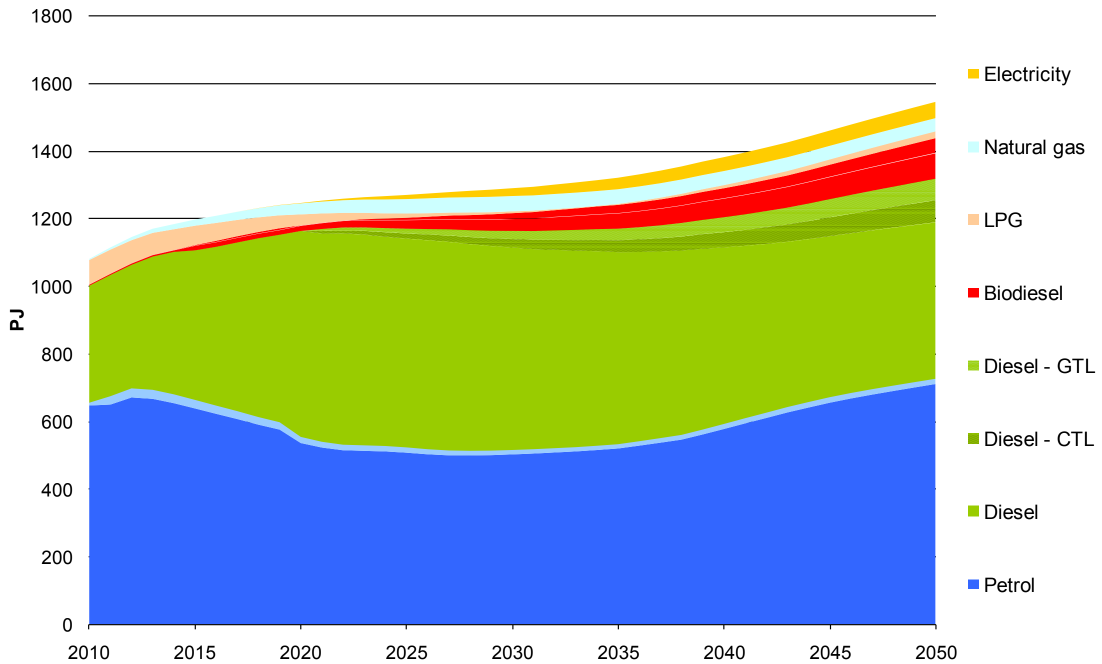

Figure 4-3: Road transport fuel consumption by fuel, Medium global action scenario

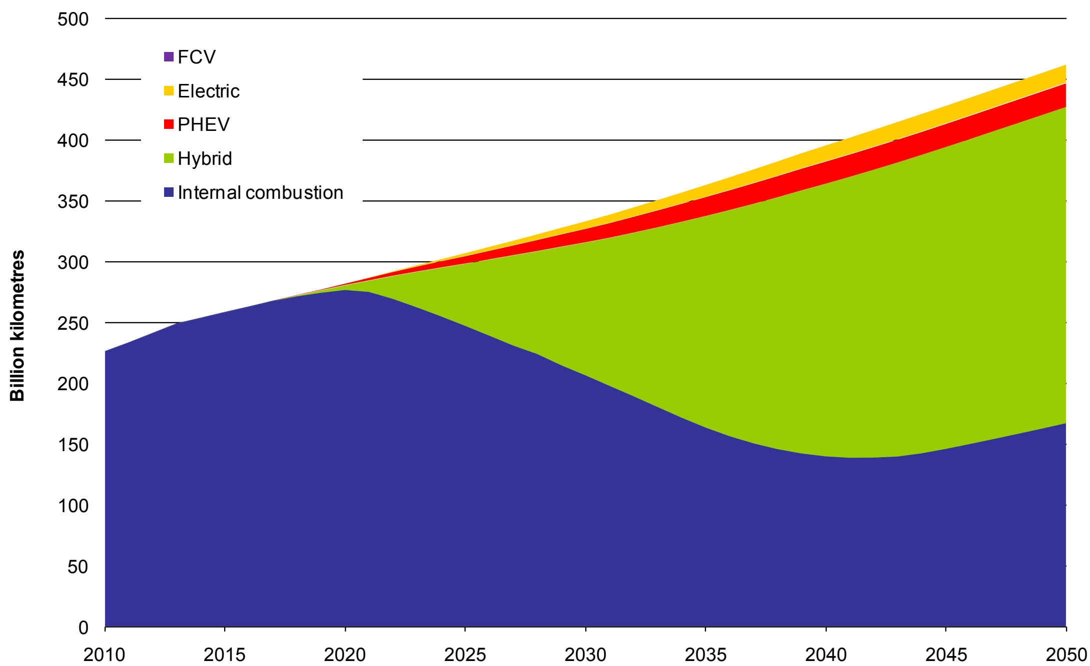

Figure 4-4: Engine type in road kilometres travelled, Medium global action scenario

‗Mild' hybrid vehicles (i.e. those without a plug-in capability) become the predominant vehicle technology in the Australian vehicle fleet by 2050, while plug-in hybrid electric vehicles (PHEV) and fully-electric vehicles (EV) are projected to play only a limited role in terms of kilometres travelled under Medium global action. Figure 4-4 shows that the large scale uptake of mild hybrids commences from the end of the present decade. These decisions are made in the presence of oil prices above US$100/bbl in real terms, and where the cost of hybrid vehicles approaches those of ICE vehicles around 2030. This finding does not ignore the fact that hybrids have already been taken up in small numbers. Rather, the modelling identifies the point at which the majority of new vehicles are projected to be mild hybrids.

Figure 4-5 shows that emissions increase at slightly less than the rate of fuel consumption. This is because the emission intensity of fuels is also declining. Greater electrification together with increasing use of biofuels and natural gas reduce the average emission intensity of transport fuel. The impact is the greatest in the period between 2020 and 2035 when growth in lower emission fuels is strongest leading to a period where emissions flatten out and decline slightly. However, beyond 2035, emissions rise more strongly as improvements in fuel efficiency and emission intensity are outpaced by demand growth.

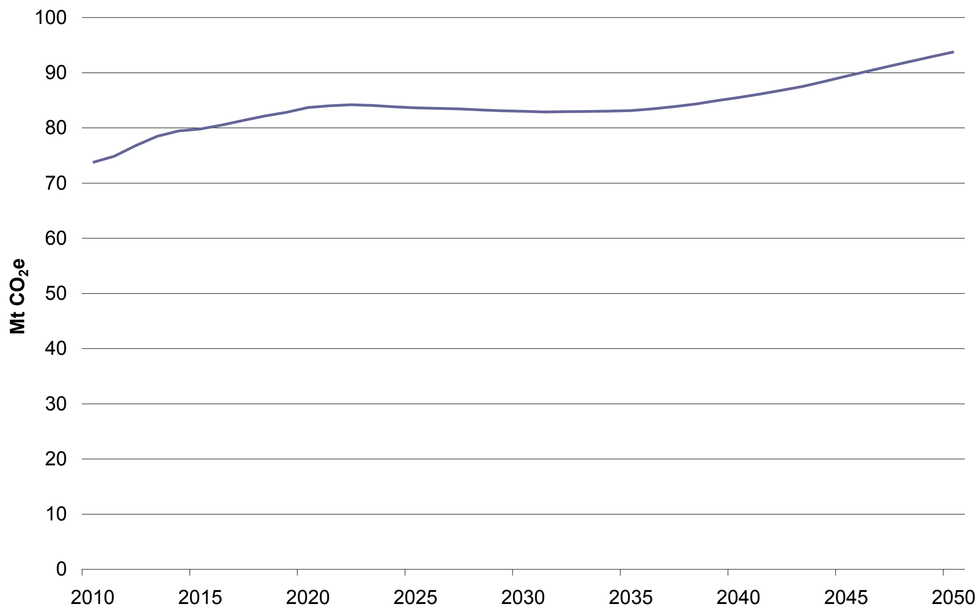

Figure 4-5: Road transport greenhouse gas emissions, Medium global action scenario

4.2 Ambitious global action scenario

The Ambitious global action scenario is very similar to the Medium global action scenario. The major difference is that, owing to greater greenhouse gas abatement activity taking place in the rest of the world, Australia has access to slightly lower cost hybrid and electric vehicles. However, this difference is not enough to make a major change to the Australian road transport sector modelling results. For consistency, the various model outputs are included below. However the discussion of the results is limited to the following minor differences to the Medium global action modelling results by 2030:

- Hybrid and electric vehicles are responsible for 660 million kilometres more travel.
- Electricity consumption by the transport sector is 0.2 TWh higher and consumption of other transport fuels is 2.6 PJ lower.
- Total road transport fuel consumption is 1.9 PJ lower.
- There is a negligible increase in VKT most likely reflecting the decrease in the cost of travel.
- Road transport sector greenhouse gas emissions are 0.2 $MtCO_2e$ lower.

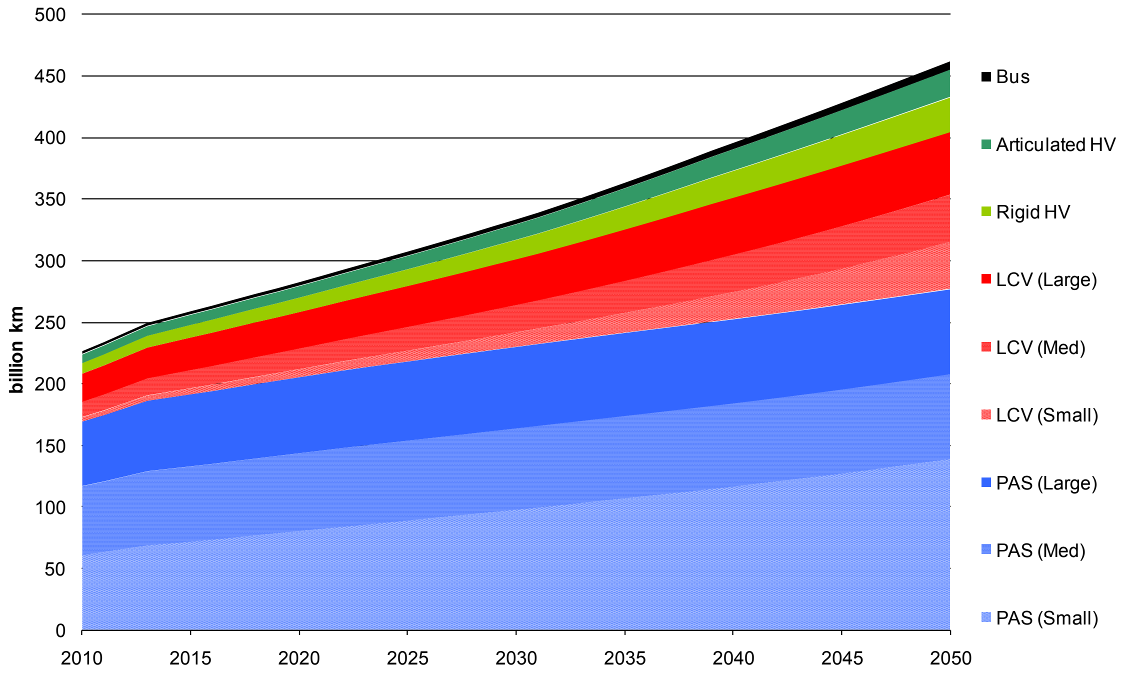

Figure 4-6: Road sector transport demand by mode, Ambitious global action

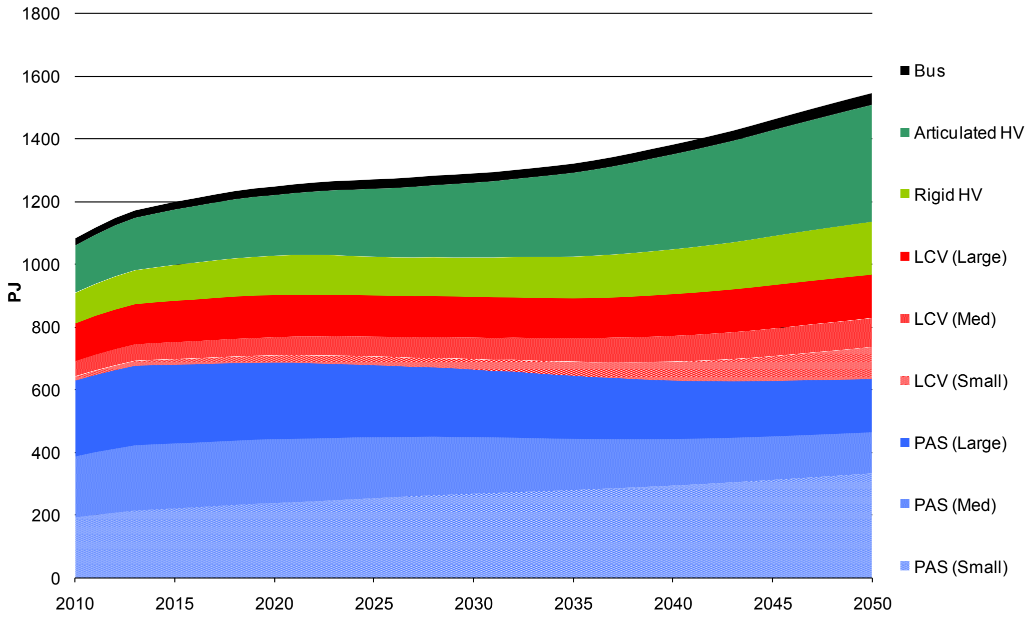

Figure 4-7: Road transport fuel consumption by mode, Ambitious global action

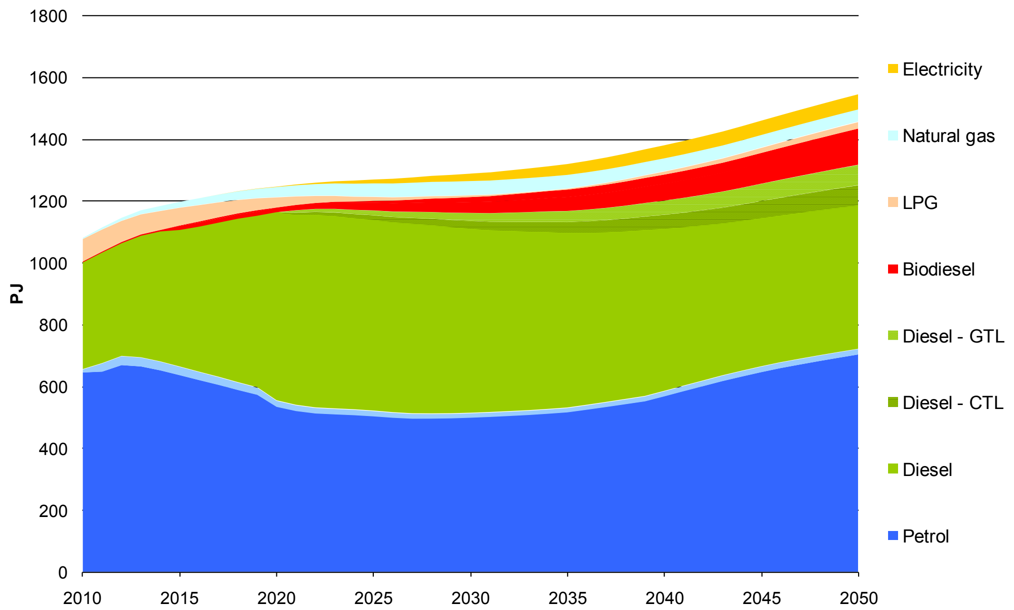

Figure 4-8: Road transport fuel consumption by fuel, Ambitious global action

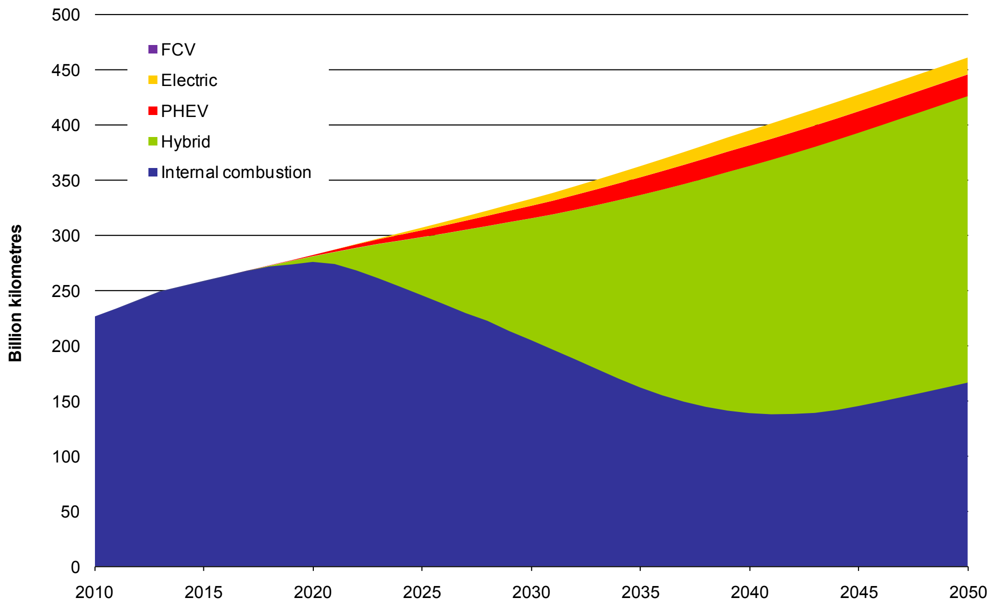

Figure 4-9: Engine type in road kilometres travelled, Ambitious global action

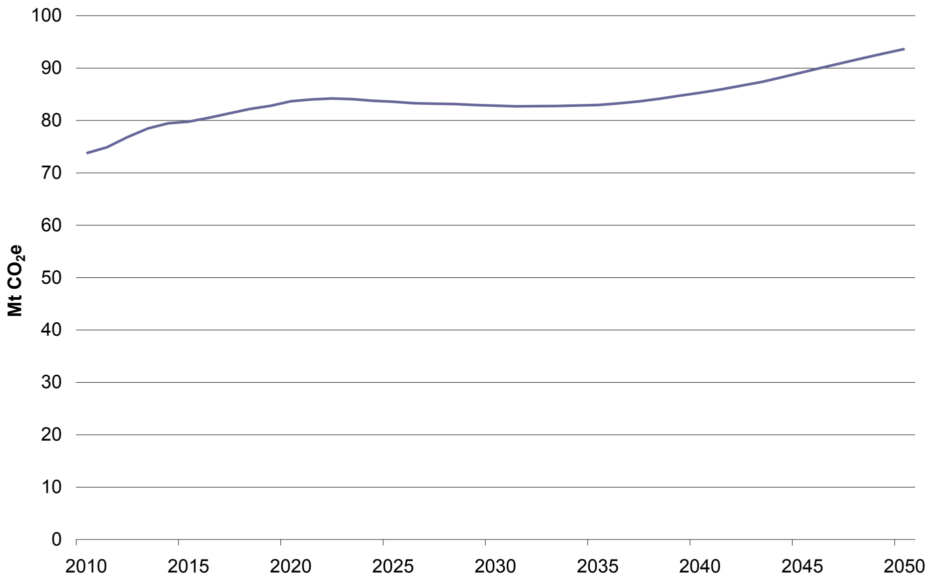

Figure 4-10: Road transport greenhouse gas emissions, Ambitious global action scenario

4.3 Core policy scenario

Under this scenario, the starting carbon price is $18.50/t in 2009-10 dollars ($20 nominal) rising 5% real for 3 years then floating. The carbon price is applied to the combustion of liquid fuels in road freight and road passenger vehicles from 2014-15, with the exception of light commercial vehicles and private transport which are shielded from the effects of the carbon price indefinitely. Gaseous fuels are also excluded from the carbon price.

This scenario assumes the same level of VKT growth for passenger and light commercial vehicles as the Medium global action scenario whilst the heavy duty sector has a slightly reduced level of demand due to the carbon price. This leads to a level of VKT in 2050 that is lower than, but closest to, the Medium global action at 460 billion kilometres.

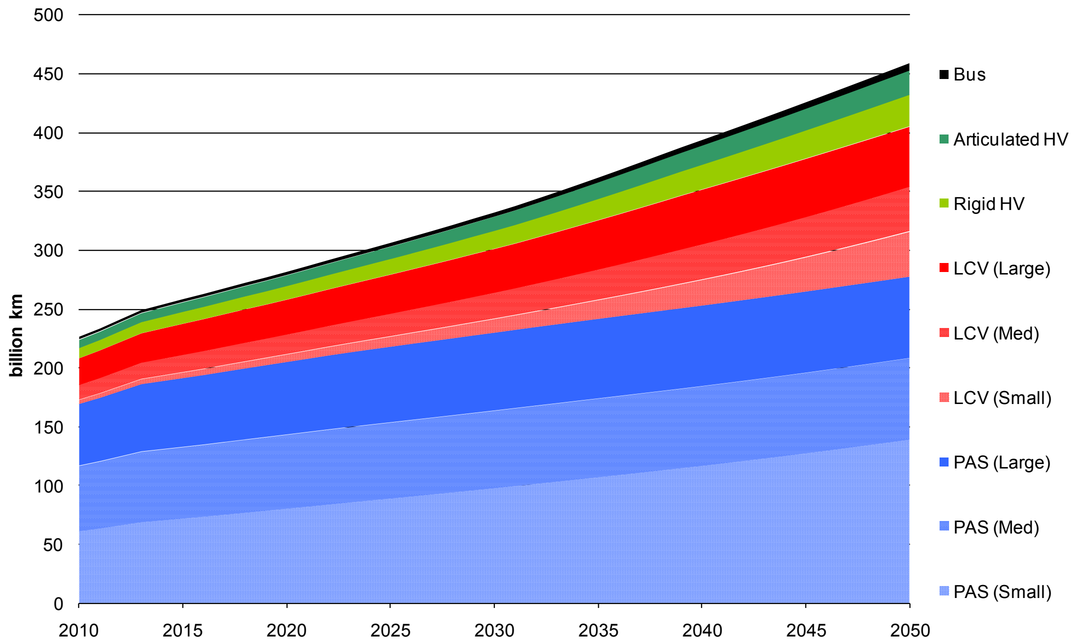

Figure 4-11: Transport demand by mode and road vehicle type, Core policy scenario

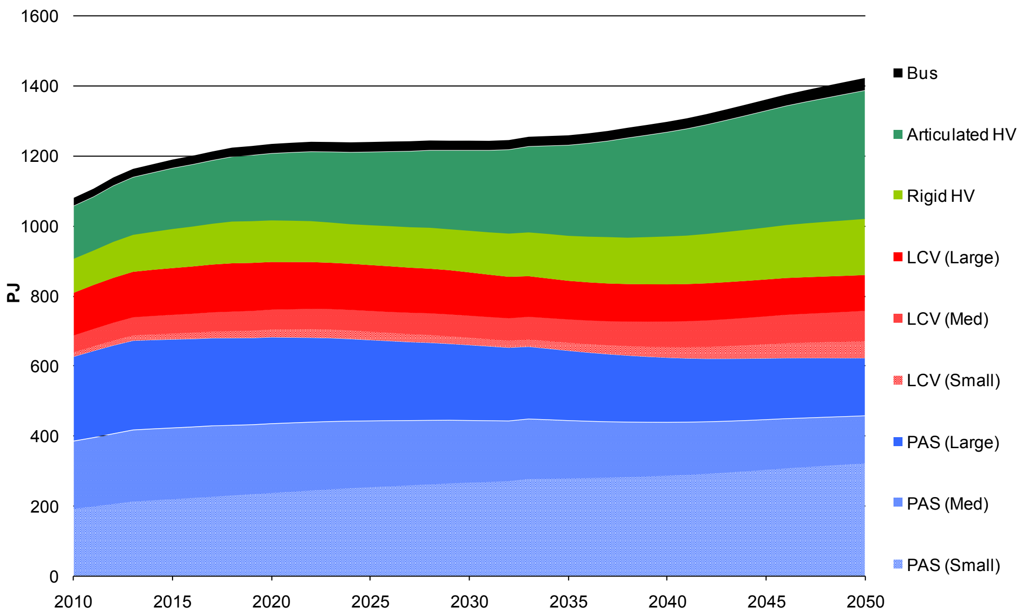

Figure 4-12: Road transport energy consumption by mode, Core policy scenario

The fuel mix resulting from this scenario reflects the freight and passenger components of the transport sector both being exposed to different incentives and having available different opportunities. In response to the carbon price signal received, the freight sector is electrifying the limited portions of that sector that are suitable for short haul transport (e.g. rigid trucks in urban areas) whilst adopting biodiesel and liquefied natural gas in articulated trucks. In the very long term there is even limited adoption of fuel cell trucks.

The passenger and light commercial sector receive no carbon price signal but nevertheless do take up some low emission fuel and engine technologies. This is due to a spill over effect between the passenger and freight sectors which is an assumption of the modelling framework. That is, it is assumed that, if the freight sector stimulates demand for biofuel production or vehicle electrification, then more cost competitive biofuels are available and more hybrid and electric vehicles are supplied to the whole road transport sector.

The basis for this assumption is the observation that biofuel refineries are likely to produce multiple products and it is a feature of the refinery industry that core profits are made on one product line while supplying many others. Economies of scale in refining might also dictate that refineries target not just the freight transport sector. In the electric vehicle market, vehicle sales support dictates that some domestic parts manufacturing and servicing as well as other infrastructure (e.g. refuelling) will be developed locally. This common infrastructure will similarly support penetration of vehicle electrification beyond the freight sector.

With oil prices increasing throughout the projection period, this increased supply of low emission alternative fuels (and their infrastructure) is incentive enough for the passenger and light commercial sectors to change their fuel mix. Consequently, the model does project a reduction in fuel consumption and emission intensity of passenger and light commercial vehicle transport relative to the Medium global action scenario.

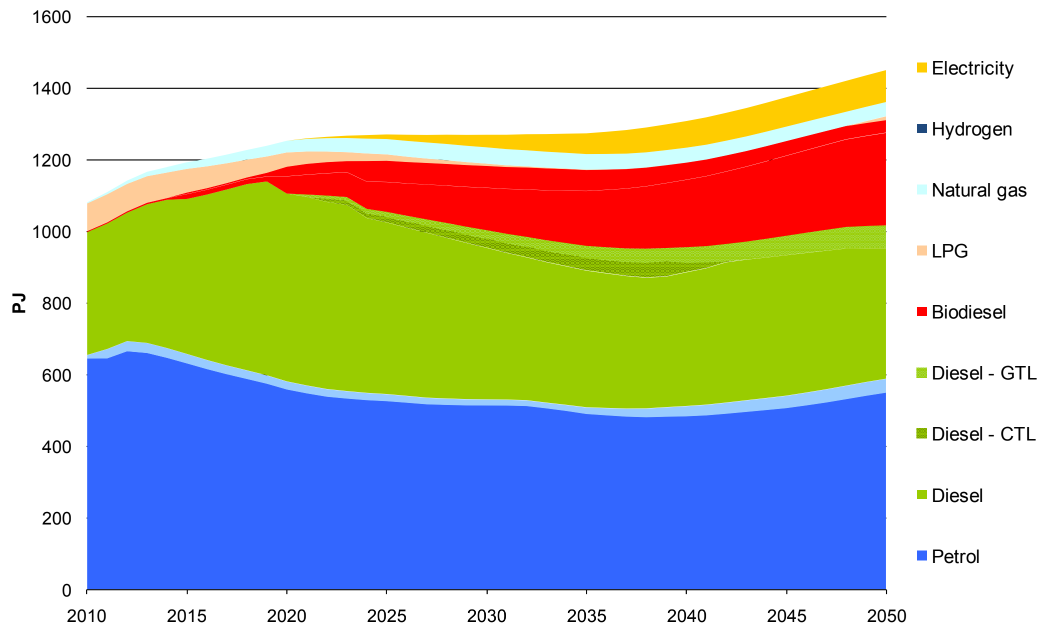

Figure 4-13: Road transport fuel consumption by fuel, Core policy scenario

Figure 4-14 provides more detail about the adoption of alternative engine types under the Fuel offset sensitivity. The uptake of electric and hybrid electric vehicles is double that of the Medium global action scenario.

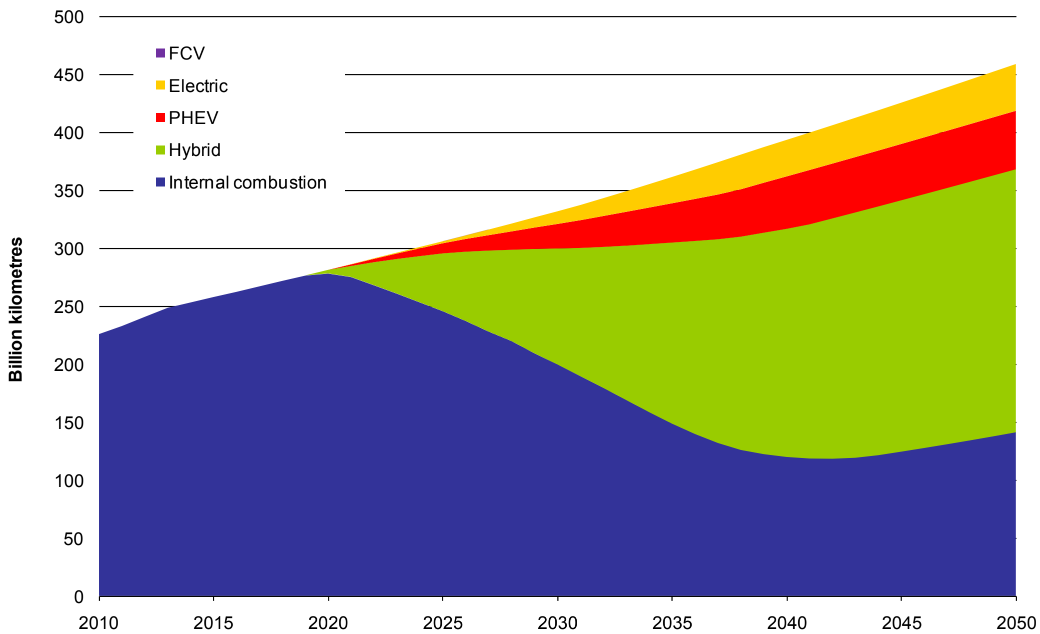

Figure 4-14: Engine type in road kilometres travelled, Core policy scenario

Figure 4-15 shows the difference between greenhouse gas emissions from road transport in the Medium global action and Core policy scenarios.

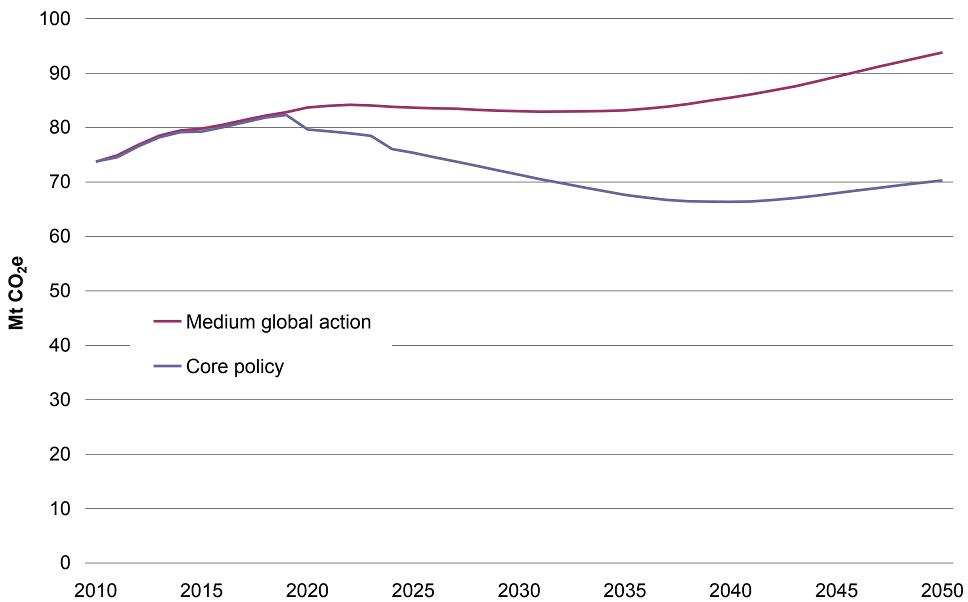

Figure 4-15: Road transport greenhouse gas emissions by fuel, Core policy scenario

The core policy shields the private passenger and light commercial vehicle segments indefinitely from a carbon price so any abatement achieved is only due to the response in the freight sector and some spill over from common infrastructure development. It takes several years for the necessary infrastructure in biofuel refining and electrification to be available. Consequently emissions do not significantly diverge from the Medium Global action scenario until the end of the present decade. By 2050 greenhouse gas emissions in the Core policy scenario are 23.5 $MtCO_2e$ lower at 70.3 $MtCO_2e$.

4.4 High-price scenario

In this scenario, a carbon pricing scheme is adopted, assumed to commence on 1 July 2012, with a national emissions target of 25 percent below 2000 levels by 2020 and 80 percent below 2000 levels by 2050. The starting carbon price is $27.50/t in 2009-10 dollars ($30 nominal) rising 5% real for 3 years then floating. Fuel tax offsets as outlined in Section 3.1 are implemented.

In contrast to the Core policy scenario this scenario presents a much stronger carbon price signal throughout the projection period and extends the carbon price signal to all fuels and vehicle types (notwithstanding the fuel tax offset period). By the end of the projection period, the carbon price is just over double that of the Core policy scenario.

The assumed level of VKT demand growth is lower in this scenario than in the Ambitious global action scenario owing to the impact of the carbon price. By 2050 the total road VKT is 428 billion kilometres which is 7.4 percent lower than Ambitious global action.

The fuel tax offset arrangements in this scenario mean that a carbon price signal is not felt in the freight and passenger markets until beyond 2013 and 2015 respectively. To put the impacts of a carbon price into scale, if the cost were to be fully passed through, each $10/t of carbon price would add around 2.5 cents per litre to the petrol price. This increase in the cost of petroleum based fuels encourages uptake of lower carbon intensive fuels. This occurs even while the effects of the carbon tax are muted by the fuel tax offset because the ESM modelling framework assumes that consumers are forward looking and take into account future changes in fuel costs when making a vehicle purchase decision.

The lowest carbon intensive fuels are electricity and biofuels and greater uptake of these fuels is the main feature of the High-price scenario relative to Ambitious global action (Figure 4-2318). As discussed earlier, the combustion emissions of biofuels are taken to be zero for the purposes of carbon price liability.

Electricity consumed in transport will also not directly attract a carbon price but will cost more to purchase from the grid as electricity generators upstream seek to recover the carbon price liabilities they incur at the point of generation. Given that electricity costs per km are one fifth that of petrol as a transport fuel (see Appendix A for more details on vehicle efficiencies and costs) and also that petrol prices are assumed to be rising, the increasing cost of electricity that is expected is not likely to be a limiting factor in road transport electrification.

The high efficiency of hybrid and electric vehicles is the main reason why the modelling projects a decline in total road transport fuel consumption in the period between 2025 and 2035. Electric motors have relatively small energy losses compared to internal combustion engines.

Note that energy losses from conversion of fuel such as coal into electricity generation are not included in transport fuel use, only the direct use of electricity and other fuels (similarly, conversion losses in refining oil into petroleum products are also not included).

The early adoption of ethanol in the period between 2010 and 2020 largely reflects the use of agricultural by-products that are presently available, which are relatively low cost to refine. The support of the New South Wales biofuels mandate is also important in securing demand for ethanol in this period. From 2020 onwards the expansion in biofuel consumption reflects the development of so called next generation biomass feedstocks. These include lignocellulose resources such as forest residues and biologically derived oils from non-agricultural feedstocks such as algae.

Some of these non-food biomass feedstocks are already available but are currently high cost. Others feedstocks such as new coppice eucalyptus plantations or algae production facilities would need to be developed over time. These new feedstocks are assumed to be unavailable until 2020. The complete list of feedstocks and their assumed costs are outlined in Appendix A.

One feature of the modelling is that the refining pathway for biomass to biodiesel is more preferred than that for biomass to ethanol (although both expand under a carbon price). This mainly reflects the fact that diesel is less replaceable in the long run. While passenger and light commercial vehicles can be electrified and their efficiencies significantly improved, the freight sector is less amenable to electrification due to a significant long haul component with high fuel needs, particularly in relation to articulated trucks (Figure 4-224-17).

Towards the end of the projection period, coal to liquids (CTL) fuel consumption ceases. This reflects its higher emission penalty which increases its cost relative to other diesel fuels. This occurs even though CO_2 capture and storage is assumed to reduce its fuel life-cycle emissions factor (see Appendix A for details of emission factors applied).

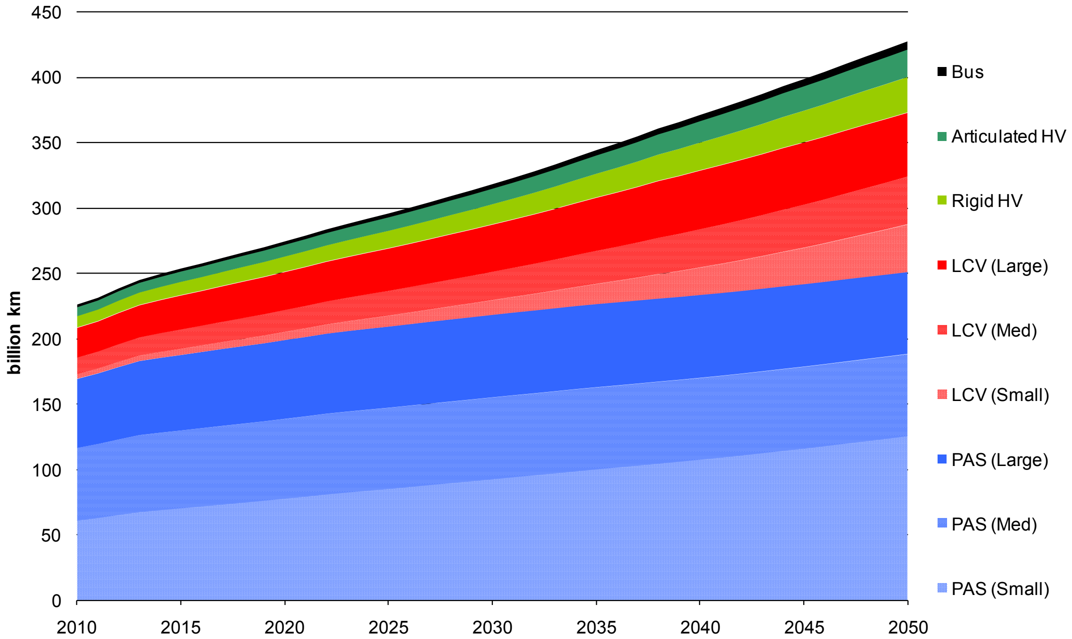

Figure 4-16: Transport demand by mode and road vehicle type, High-price scenario

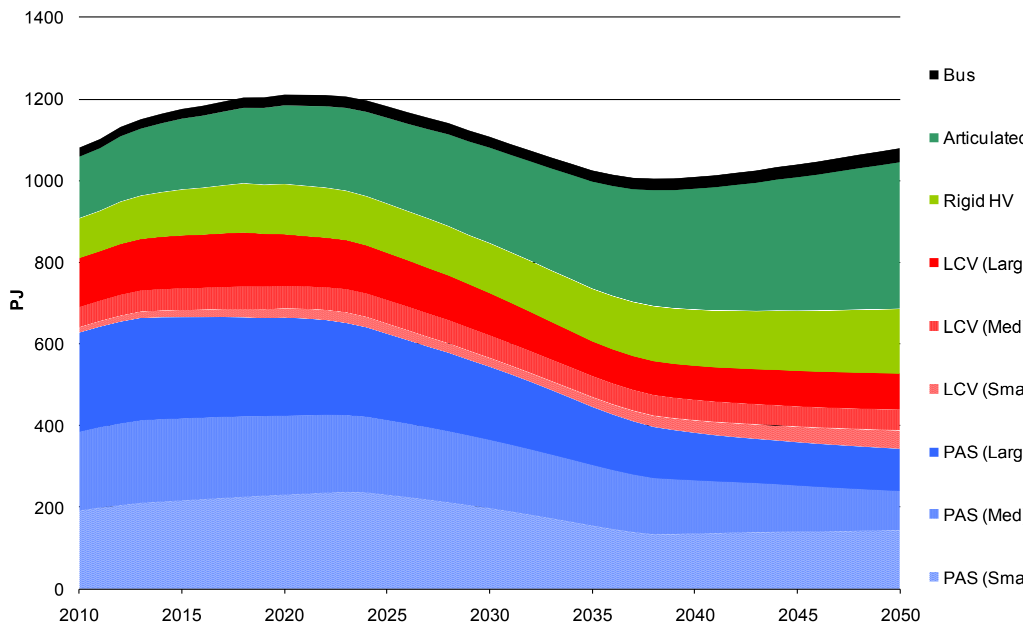

Figure 4-17: Road transport energy consumption by mode, High-price scenario

The High-price scenario results in a 30.2 percent reduction in fuel consumption relative to the Ambitious global action. This compares to around a 6 percent reduction under the Core policy scenario. Total road transport fuel consumption in 2050 under High-price is 1079 PJ.

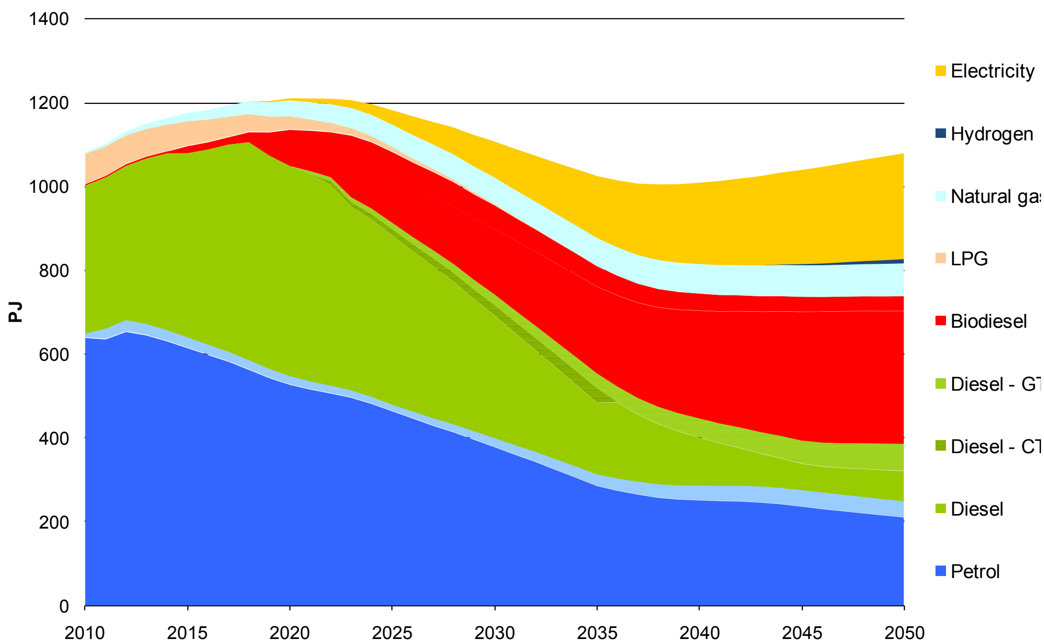

Figure 4-18: Road transport fuel consumption by fuel, High-price scenario

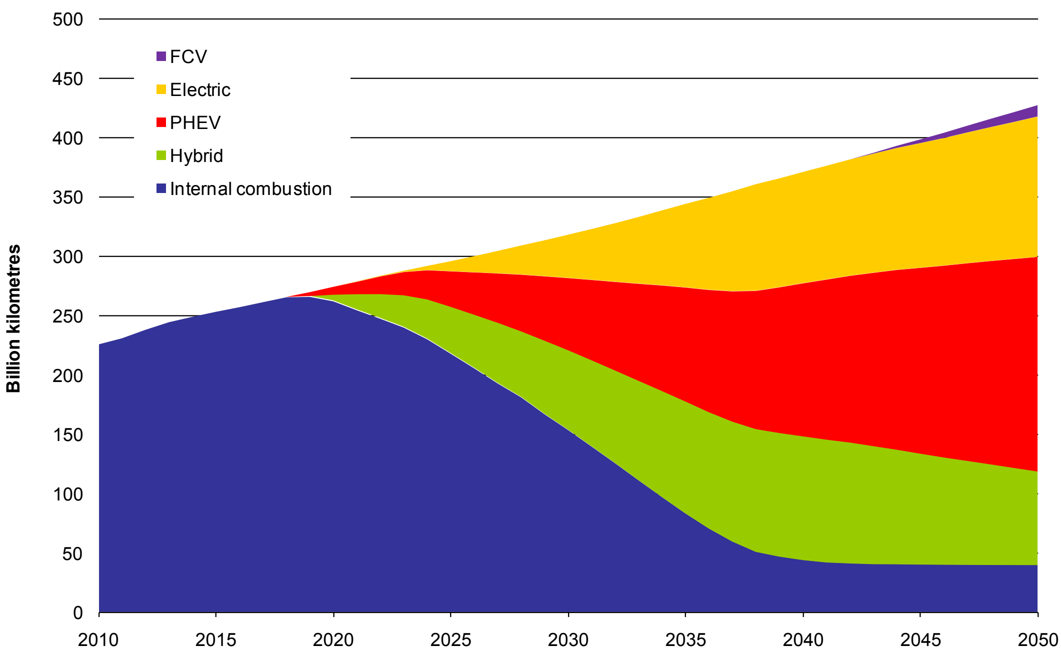

Figure 4-19: Engine type in road kilometres travelled, High-price scenario

The substantial reduction road transport fuel consumption reflects the high rate of vehicle electrification in this scenario.

As indicated, hybrid and plug-in hybrid electric vehicles begin to be cost competitive from just before 2020 followed by fully electric vehicles a few years later. This reflects the assumption that hybrids initially present lower cost. On the other hand, although plug-in hybrids will be a more expensive option, they offer significant fuel savings in the larger passenger vehicle segment which is assumed to be of less relevance to electric only vehicles.

Hydrogen fuel cell vehicles enter the fleet toward the end of the projection period. Fuel cell vehicles offer the extended range of a petrol driven vehicle but with the use of a near zero emission fuel (assuming the hydrogen is produced from electrolytic hydrolysis and the electricity sector decarbonises over time). Fuel cell vehicles become more competitive as both their costs reduce and petroleum product prices (inclusive of carbon liabilities) continue to rise.

Electricity accounts for a quarter of all road transport fuel and more than half of the kilometres driven by 2050 (Figure 4-18 and Figure 4-19). This amounts to a demand for 70 TWh of electricity by 2050. PHEVs eventually occupy the largest share of vehicle engine types by 2050. This reflects the assumption that some vehicle segments will still require long range capability.

Figure 4-20 shows that GHG emissions from road transport begin to decline significantly earlier than seen under the Core policy scenario, reflecting earlier uptake of electric vehicles. Relative to the Ambitious global action scenario, emissions begin diverging as soon as a carbon price is built into future expectations. By 2050, High-price scenario emissions are 69.7 percent below Ambitious global action.

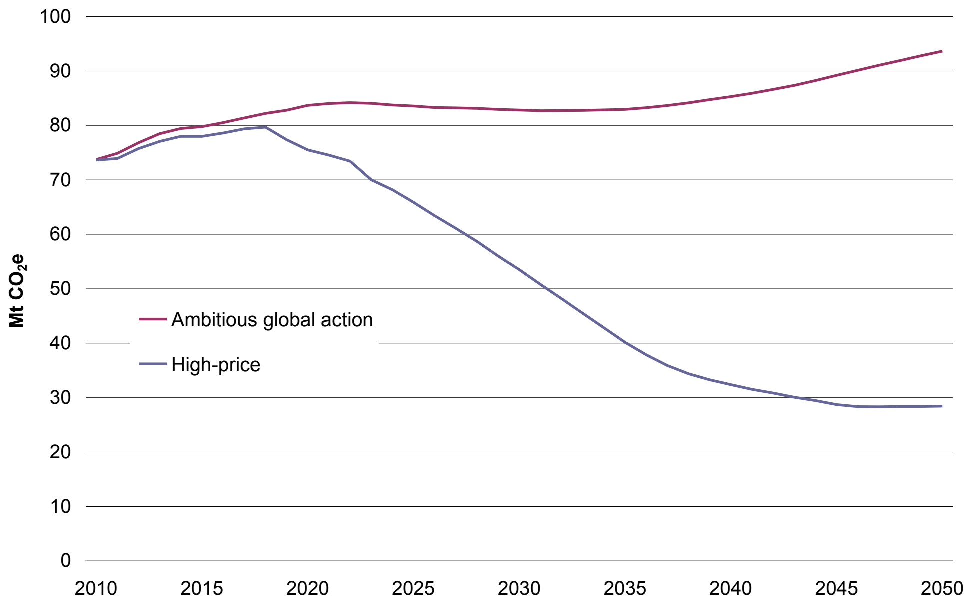

Figure 4-20: Road transport greenhouse gas emissions by fuel, High-price scenario

4.5 Low-price sensitivity

In this sensitivity a carbon pricing scheme is adopted, assumed to commence on 1 July 2012, with a national emission target of 5 percent below 2000 levels by 2020 and 80 percent below 2000 levels by 2050. The starting carbon price is $9/t in 2009-10 dollars ($10 nominal) rising 5% real for 10 years then floating. Fuel tax offsets as outlined in Section 3.1 are implemented.

Reflecting changes in economic growth and the structure of the economy from the introduction of a carbon price, the assumed rate of VKT demand growth is lower in this sensitivity than in the Medium global action scenario. By 2050 the total road VKT is 437 billion kilometres which is 5.4 percent lower than Medium global action (Figure 4-21).

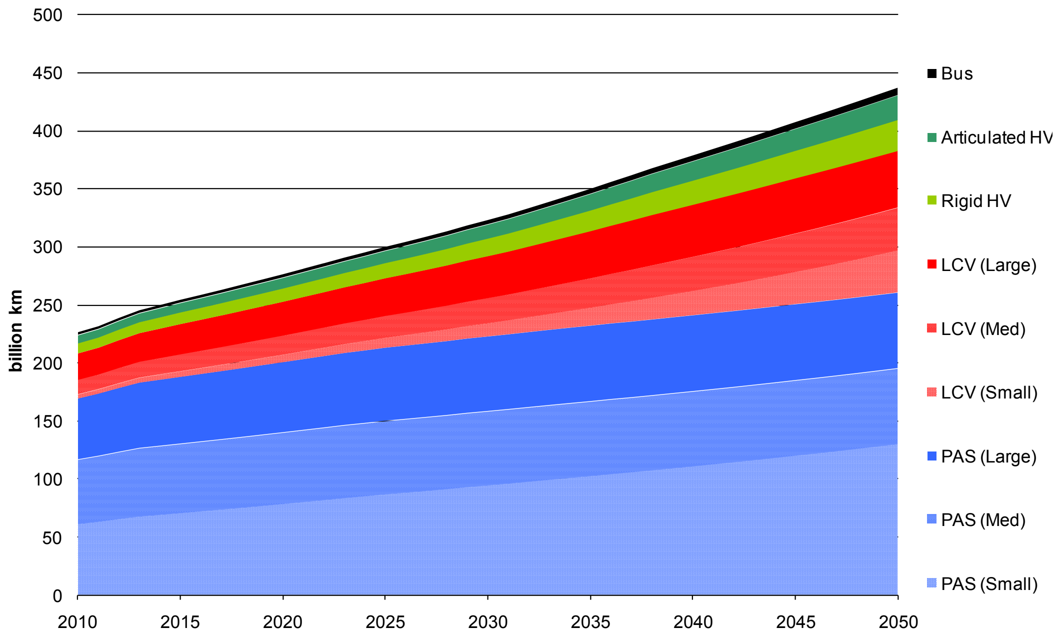

Figure 4-21: Transport demand by mode and road vehicle type, Low-price sensitivity

The changes in road transport fuel mix mirrors that of the high-price scenario however the rate of uptake of biofuels and vehicle electrification is lower over time. As a consequence diesel and petrol fuel consumption does not decline as rapidly as in the high-price scenario.

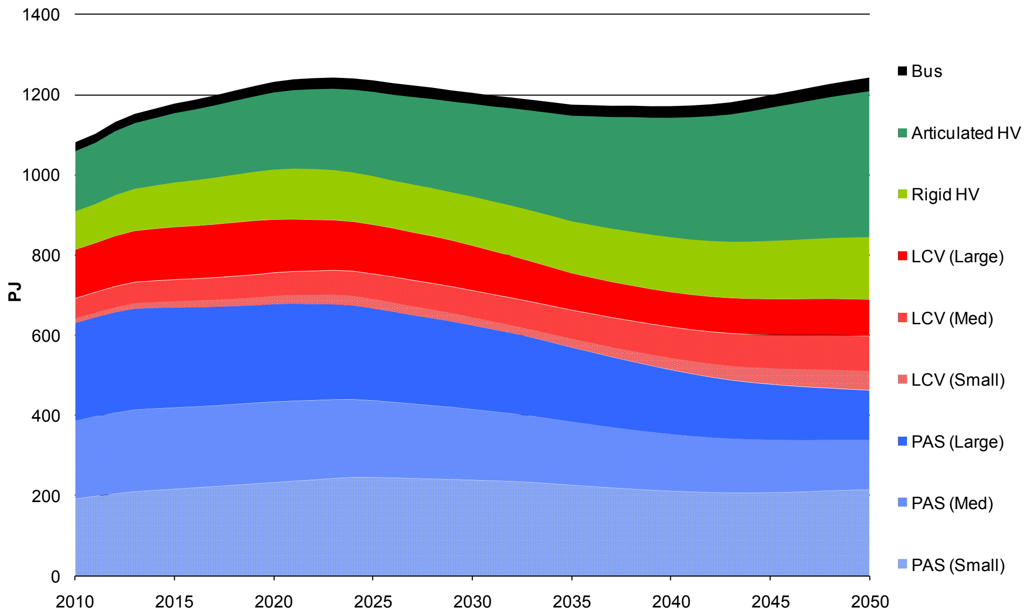

Figure 4-22: Road transport energy consumption by mode, Low-price sensitivity

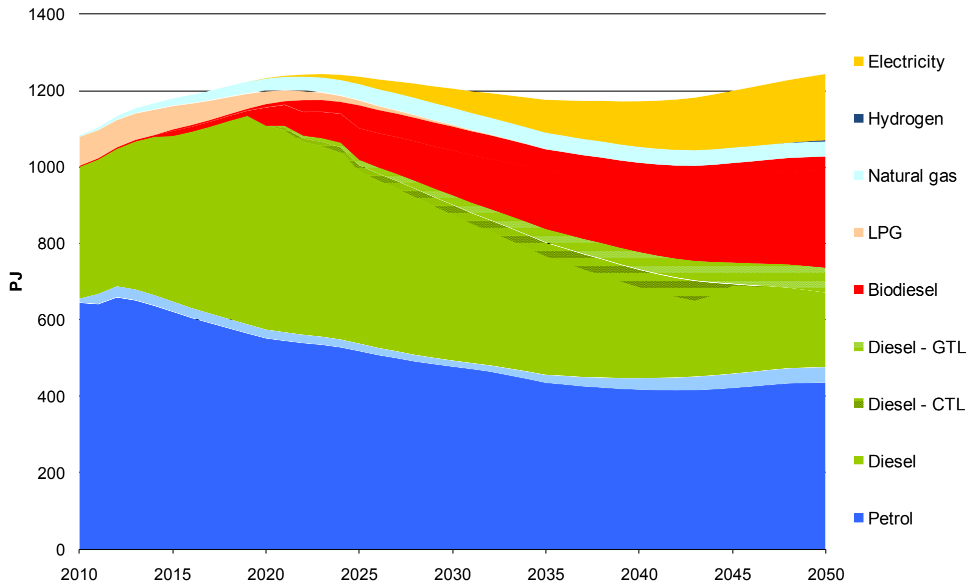

Figure 4-23: Road transport fuel consumption by fuel, Low-price sensitivity

The projected electrification of the road transport sector is shown in Figure 4-24. Vehicle electrification progresses at a moderate but lower pace from around 2020 relative to the High price scenario. Hydrogen fuel cell vehicle uptake is also lower in the low-price sensitivity than under the High-price scenario.

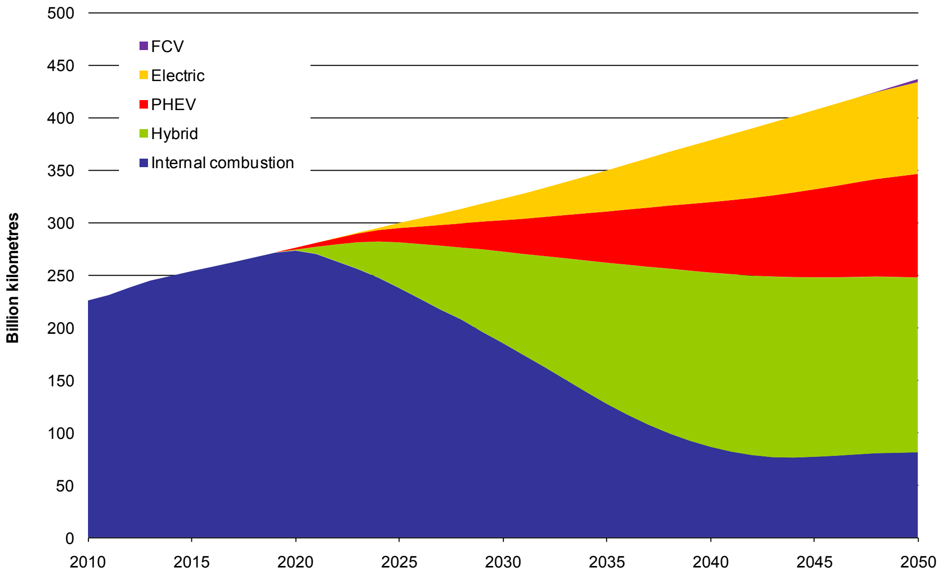

Figure 4-24: Engine type in road kilometres travelled, Low-price scenario

Greenhouse gas emissions begin diverging from the Medium global action scenario as soon as a carbon price is built into future expectations. However, both the Medium global action scenario and Low-price sensitivity emissions rise during the period to 2020 reflecting the slow change in fuel mix up to this point. After 2020, as the fuel mix begins to change more rapidly, emissions decline significantly down to 50 $MtCO_2e$ by 2050 (Figure 4-25).

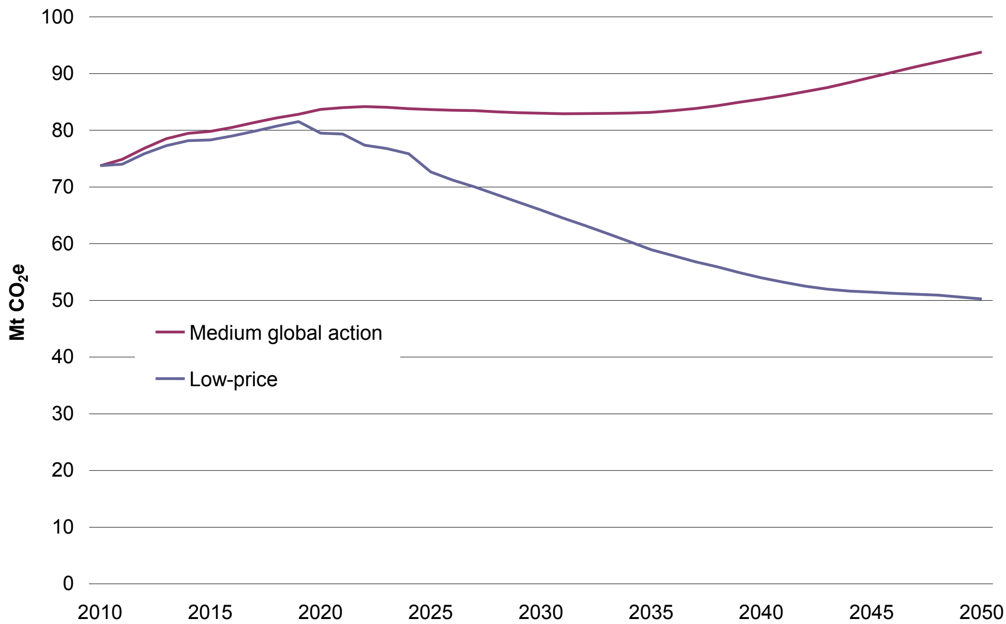

Figure 4-25: Engine type in road kilometres travelled, Low-price scenario

4.6 Medium-price sensitivity

A carbon pricing scheme is adopted with the same national target as the Core policy scenario. Fuel tax offsets as outlined in Section 3.1 are implemented. However, they are not extended for private passenger and light commercial vehicles or for use of natural gas and liquefied petroleum gas.

This scenario presents a stronger carbon price signal than the low-price scenario in the period up to 2022 (notwithstanding the fuel tax offset in the first three years). After 2022 the carbon price signal is identical.

The assumed level of VKT demand growth is lower in this scenario than in the Medium global action scenario owing to the impact of the carbon price. As for the low-price scenario, by 2050 the total road VKT is 438 billion kilometres which is 5.2 percent lower than in Medium global action.

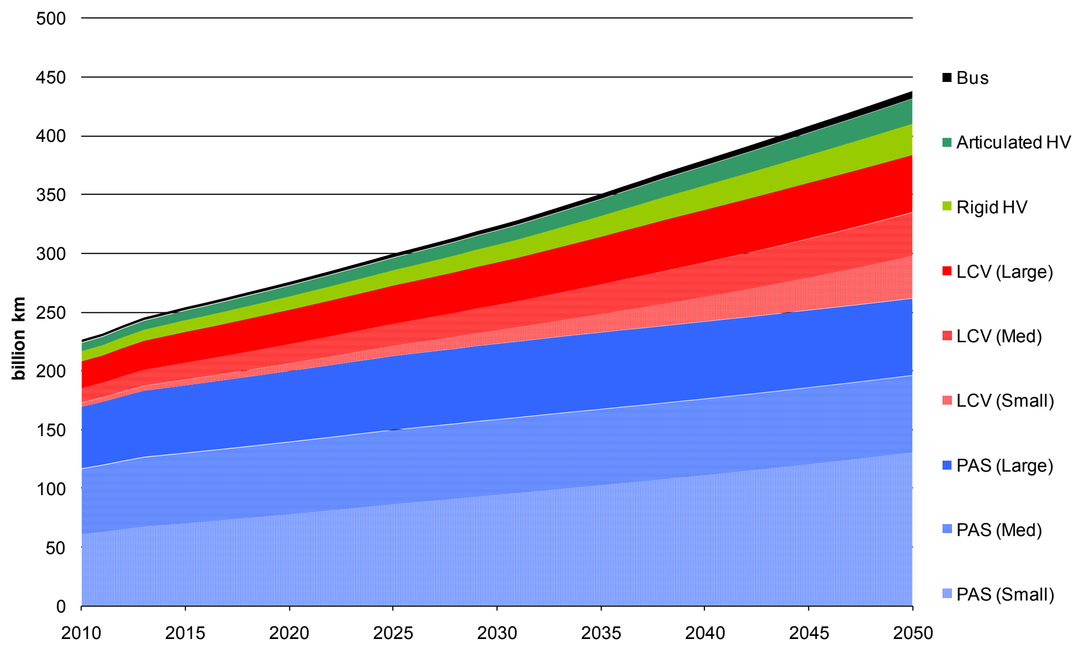

Figure 4-26: Transport demand by mode and road vehicle type, Medium-price scenario

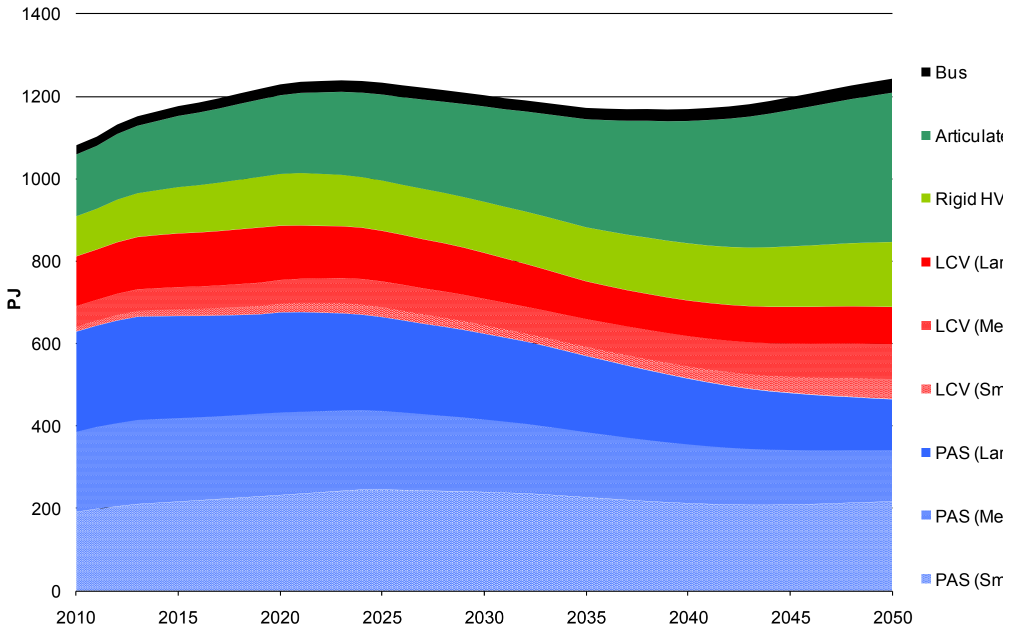

Figure 4-27: Road transport energy consumption by mode, Medium-price scenario

By 2050, in the Medium-price scenario, total road transport fuel consumption has reduced by 19.6 percent relative to the Medium global action, to 1247 PJ. This reflects the greater uptake of zero direct emission fuels such as electricity and biofuels, and to a lesser extent natural gas (Figure 4-28). This increased preference for low emission fuels closely matches the changes already described in the High-price scenario.

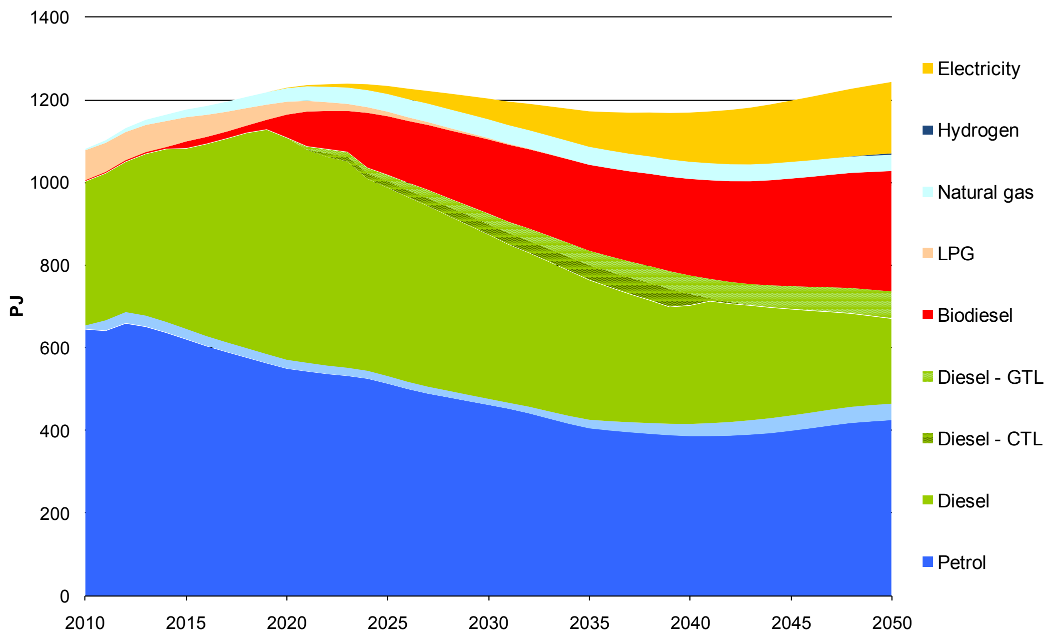

Figure 4-28: Road transport fuel consumption by fuel, Medium-price scenario

The electrification of road transport, in the form of EVs in the light passenger vehicle class and PHEVs in the heavy passenger vehicle classes, is shown in Figure 4-29. By 2050, EVs and PHEVs account for around a third of road kilometres travelled.

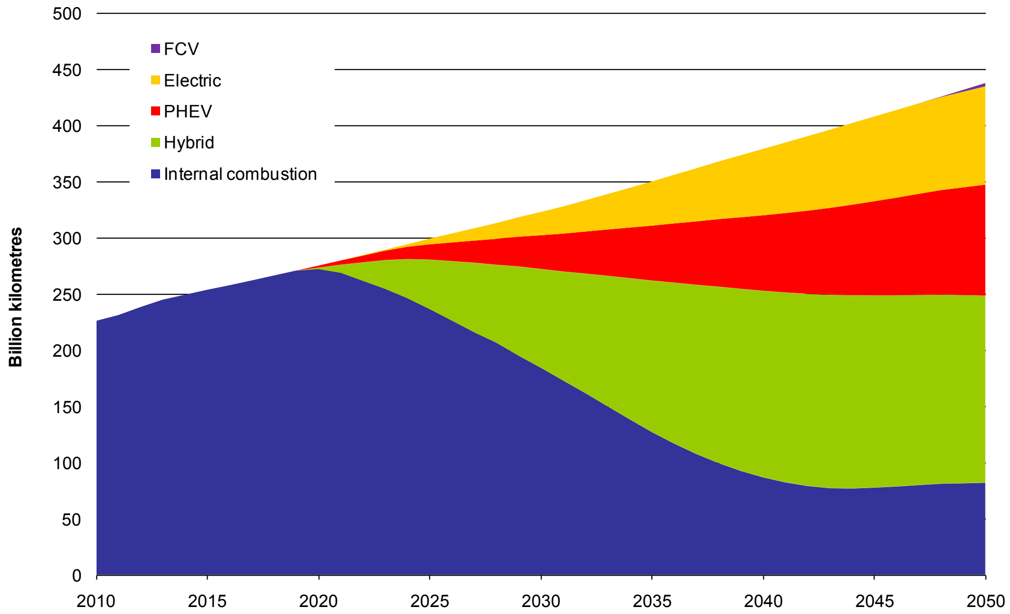

Figure 4-29: Engine type in road kilometres travelled, Medium-price scenario

Figure 4-30 shows that GHG emissions from road transport increase out to 2020, and then decline significantly as the changes in the fuel mix accelerate and offset rising VKT. Relative to the Medium global action scenario, emissions begin diverging as soon as a carbon price is built into future expectations. By 2050, Medium-price scenario emissions are 46.4 percent below those in Medium global action.

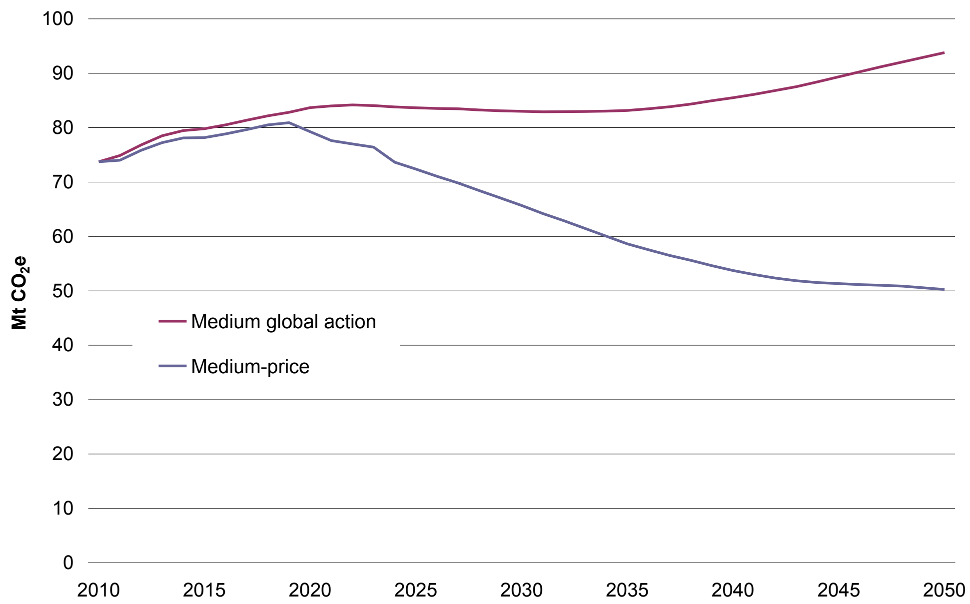

Figure 4-30: Road transport greenhouse gas emissions by fuel, Medium-price scenario

4.7 Unshielded high-price sensitivity

In this sensitivity case a carbon pricing scheme is adopted with the same national target as the High-price scenario. However, it is assumed that the carbon price is floating from the commencement of the scheme and fuel tax offsets are not available.

The main impact of this sensitivity case relative to the High-price scenario is that there is a stronger carbon price signal throughout the projection period for passenger and light commercial vehicles. Passenger and light commercial vehicles not only lose their shielding in the first three years, but also lose the permanent shielding that remains which is set at the rate provided in the last year of the 3 year offset period. Freight vehicles lose their single year of offsets assumed in the High-price scenario. However, for the remainder of the projection period the carbon price signal is identical, since their offset arrangements were anyway assumed to be only temporary in the High-price scenario.

The sensitivity case assumes the same level of VKT growth as the High-price scenario. However, the model is free to choose an alternative fuel and technology supply response to the altered carbon price signal.

In aggregate terms, road transport fuel consumption in the sensitivity case is 17 PJ lower by 2020 and 20 PJ lower by 2030. However, by 2050 the gap has narrowed with only a 3 PJ reduction below fuel consumption in the High-price scenario (1076 PJ in total). This indicates that the additional abatement opportunities triggered in the passenger and commercial vehicle market segments are economically viable under either case some time before 2050 such that there is no additional benefit from a stronger price signal at the end of the projection period.

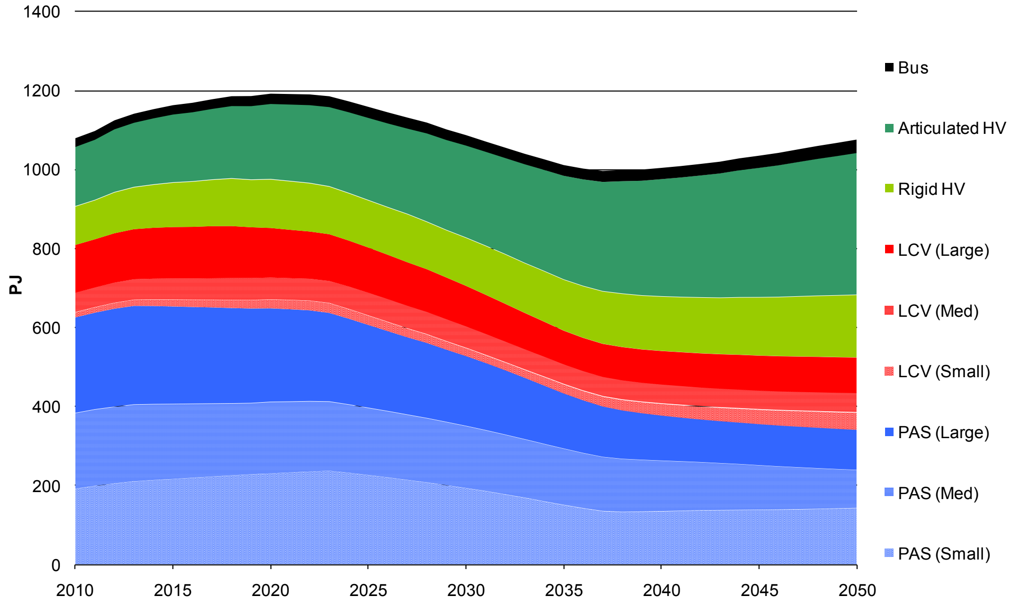

Figure 4-31: Road transport energy consumption by mode, Unshielded high-price sensitivity

The aggregate reduction in road transport fuel consumption relative to the High-price scenario in the period to 2020 is achieved by increasing both the share and absolute level of diesel fuel consumption. The total number of kilometres travelled by hybrid vehicles also increases by 25 percent relative to the High-price scenario. By 2030, the differences in fuel consumption are explained by an ongoing preference for diesel and slightly higher (2 PJ) adoption of electricity.

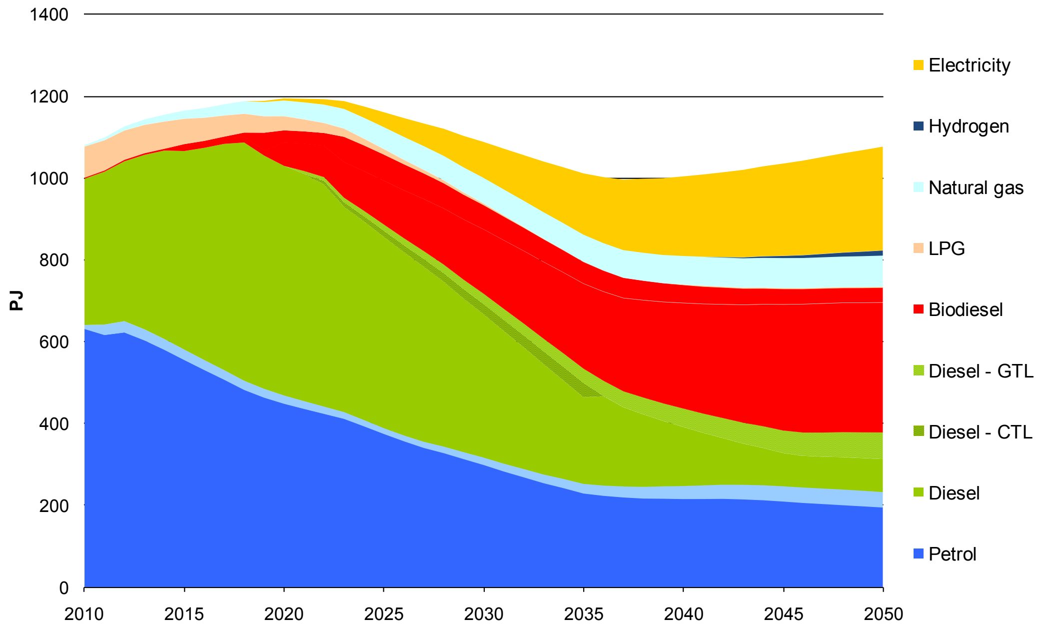

Figure 4-32: Road transport fuel consumption by fuel, Unshielded high-price sensitivity

Figure 4-33 provides more detail about the adoption of alternative engine types under the Unshielded high-price sensitivity. The pattern is very similar to the High-price scenario with small changes to the degree and timing of uptake. Large scale uptake of all alternative engine types begins one year earlier than the High-price scenario. As a result the VKT market share of internal combustion vehicles is around 2 percent lower than under the High-price scenario throughout most of the projection period, only narrowing in the last two decades.

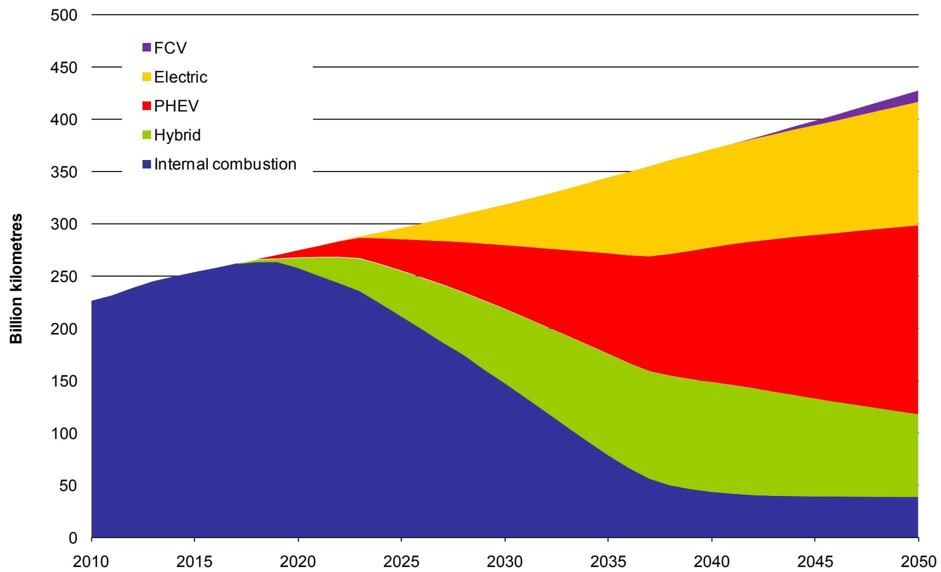

Figure 4-33: Engine type in road kilometres travelled, Unshielded high-price sensitivity

Figure 4-34 shows the difference between greenhouse gas emissions from road transport in the High-price and Unshielded High-price scenarios. It has been observed that around 20 PJ per annum of fuel was saved by removing the fuel tax offset arrangements. At a petroleum fuel emission factor of approximately 0.07 $MtCO_2e$/PJ our expectation is that around 1.4 $MtCO_2e$ should be saved in the sensitivity case. The actual amount of difference fluctuates, at a maximum of 1.7 $MtCO_2e$ in 2024 declining to 0.3 $MtCO_2e$ by 2050.

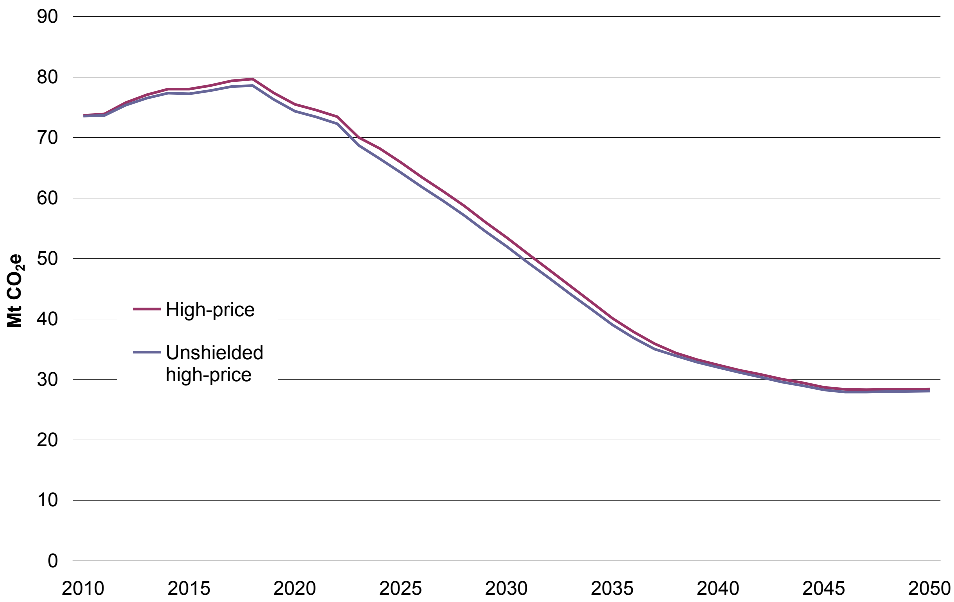

Figure 4-34: Road transport greenhouse gas emissions by fuel, Unshielded high-price sensitivity

4.8 High oil price sensitivity

In these sensitivity cases the Medium global action scenario and Medium-price sensitivity are modelled with the same assumptions except a higher oil price. There is no change in the level of VKT growth in either sensitivity case.

The main impact of the high oil price sensitivity on both the Medium global action scenario and Medium-price sensitivity is a major shift in fuel consumption from petrol to diesel. By 2050 diesel consumption is 84 PJ higher in the High oil price/Medium global action sensitivity and 233 PJ higher in the High oil price/Medium-price sensitivity.

The High oil price/Medium global action sensitivity case also exhibits greater electricity and biofuel use than the Medium global action scenario. The increase in the oil price has a similar effect to increases in the carbon price and hence the High oil/Medium global action scenario demonstrates similar fuel mix changes to those observed under the carbon price scenarios. However, the oil price improves the competitiveness of all alternative fuels, not just those with low greenhouse gas intensities. Hence, for example, coal to liquids diesel has a longer period of relevance than is generally projected under the carbon price scenarios.

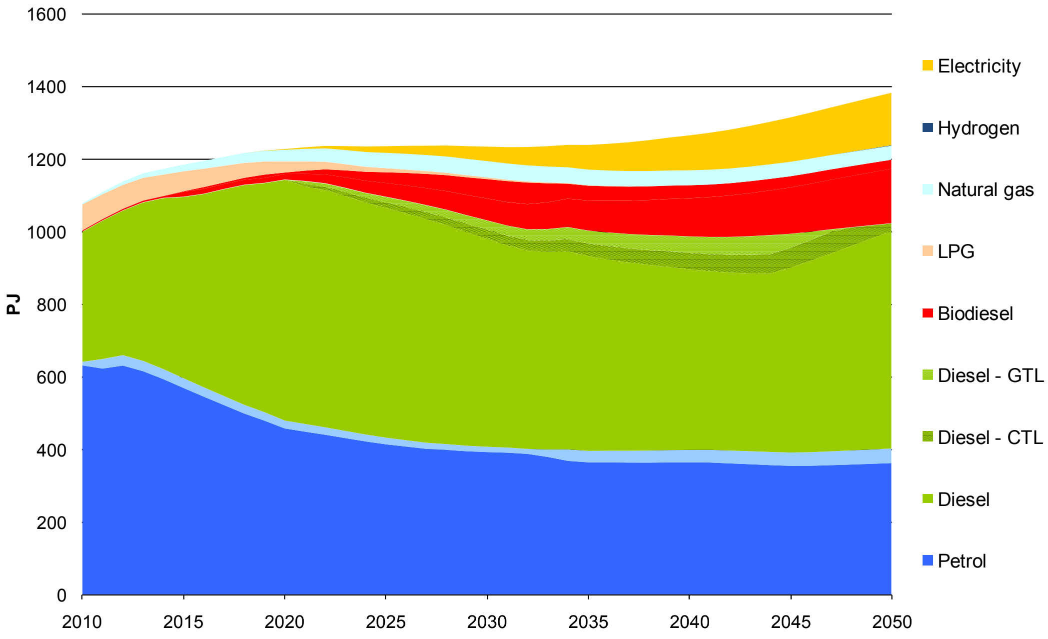

Figure 4-35: Road transport fuel consumption by fuel, High-oil/Medium global action sensitivity

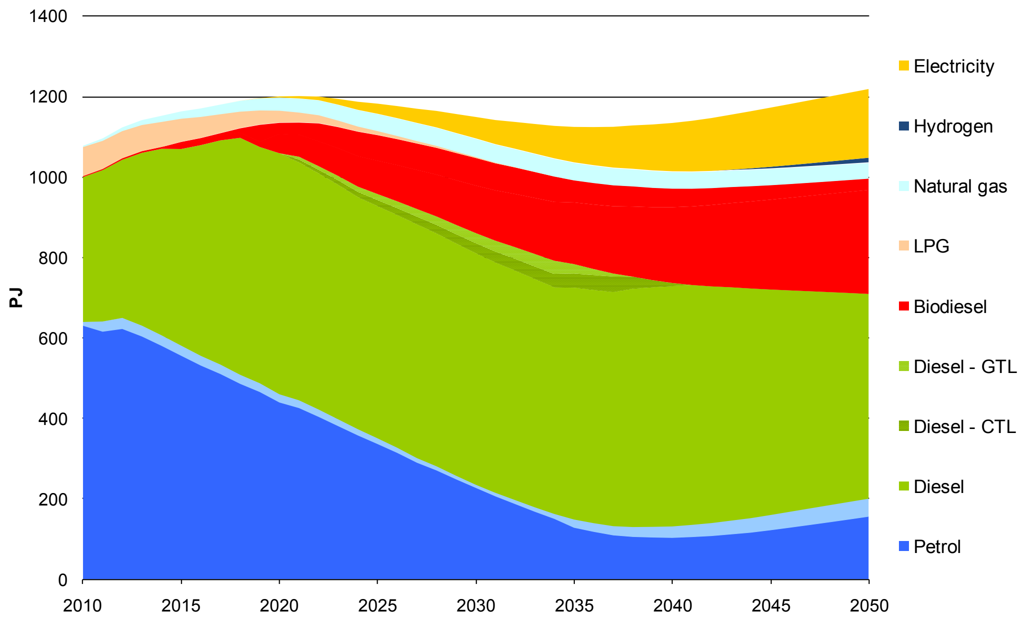

Figure 4-36: Road transport fuel consumption by fuel, High oil/Medium-price sensitivity

In terms of vehicle engine technology, the High oil price sensitivity case shows an early uptake of hybrid and electric vehicles compared to the Medium global action scenario and Medium-price sensitivity. This leads to higher uptake in the long run with greater differences between the

High oil/Medium global action sensitivity (Figure 4-37 and Figure 4-38) and Medium global action than those between High oil/Ambitious global action and Ambitious global action.

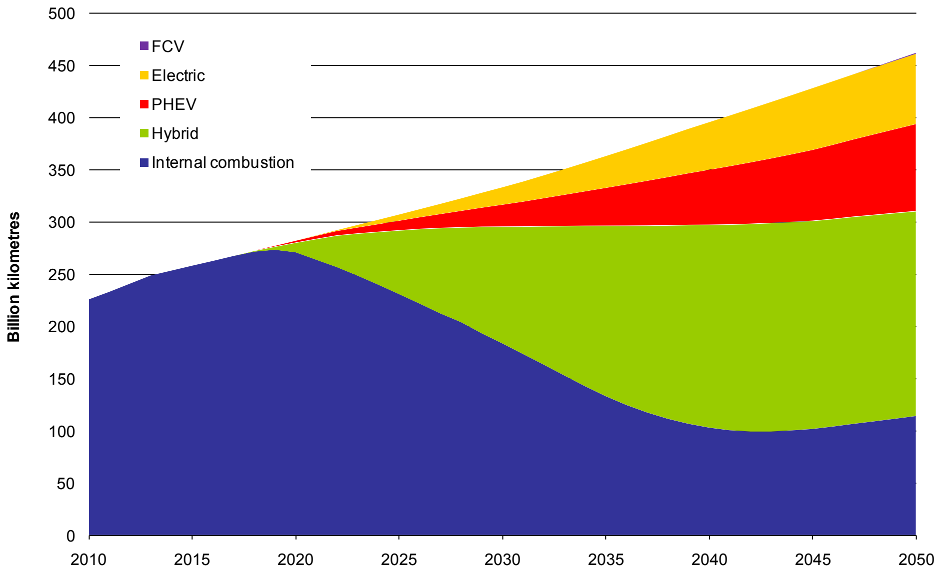

Figure 4-37: Engine type in road kilometres travelled, High oil price/Medium global action sensitivity

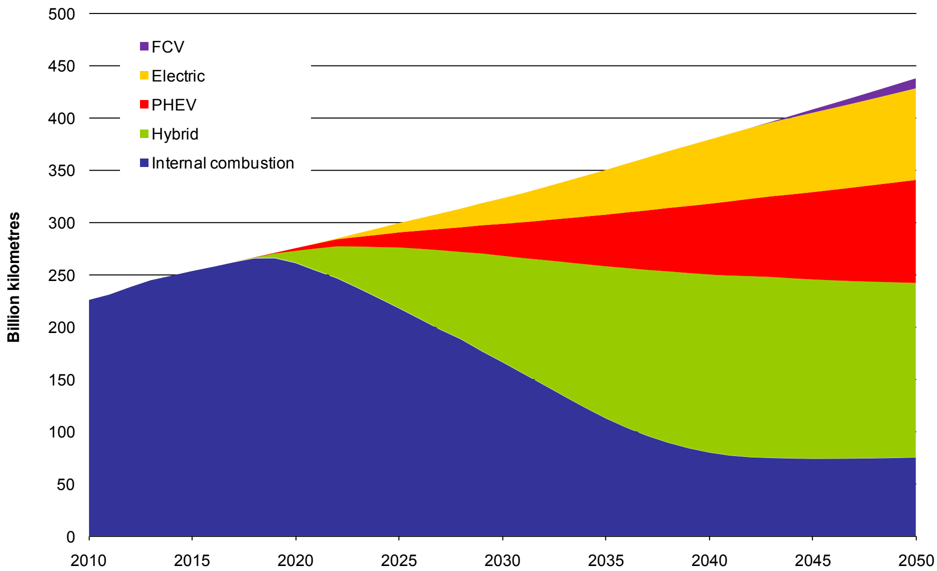

Figure 4-38: Engine type in road kilometres travelled, High oil/Medium-price sensitivity

The comparison of greenhouse gas emissions in Figure 4-39 shows that the high oil price has a significant impact, accelerating adoption of more fuel efficient vehicle choices, particularly relative to the Medium global action.

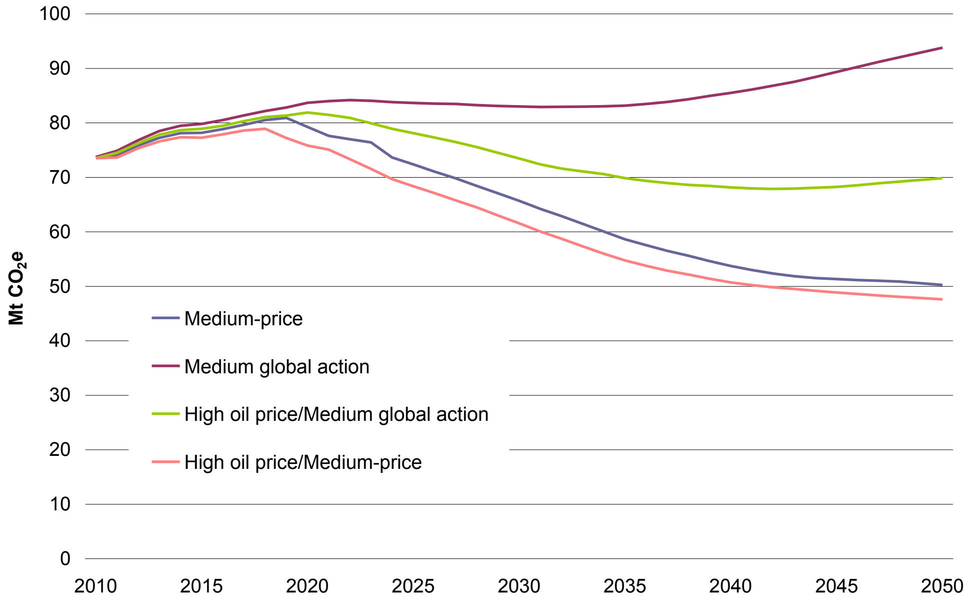

Figure 4-39: Road transport greenhouse gas emissions by fuel, High oil price sensitivity

4.9 Low oil price sensitivity

In this sensitivity case the Medium global action scenario and Medium-price sensitivity are modelled with the same assumptions except a lower oil price. There is no change in the level of VKT growth in either sensitivity case.

The main impacts of the low oil price on both the Medium global action scenario and Medium price sensitivity are largely the opposite of the high price. Specifically, the low oil price case shows a significant reduction in the extent to which diesel replaces petrol during the projection period. Also, the Low oil price sensitivity case exhibits greater inertia in the fuel mix, in contrast to the acceleration of change that was seen in the High oil price sensitivity. However, in contrast to the High oil case, the differences in fuel use are negligible before 2020.

By 2050 diesel consumption is 100 PJ lower in the Low oil price/ Medium global action sensitivity and 71 PJ lower in the Low oil price/Medium-price sensitivity.

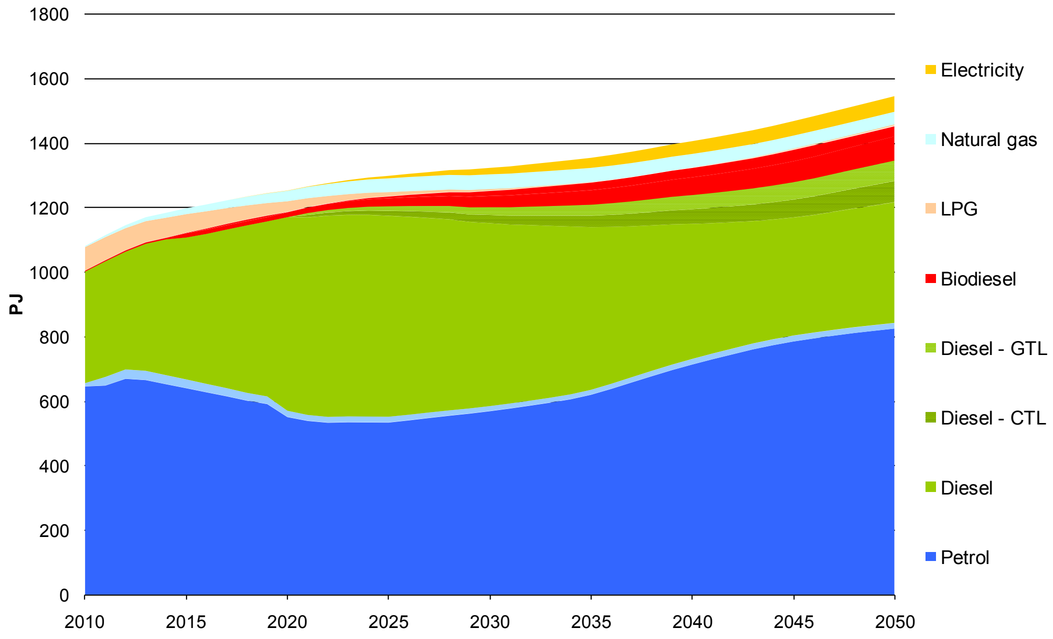

Figure 4-40: Road transport fuel consumption by fuel, Low-oil/ Medium global action sensitivity

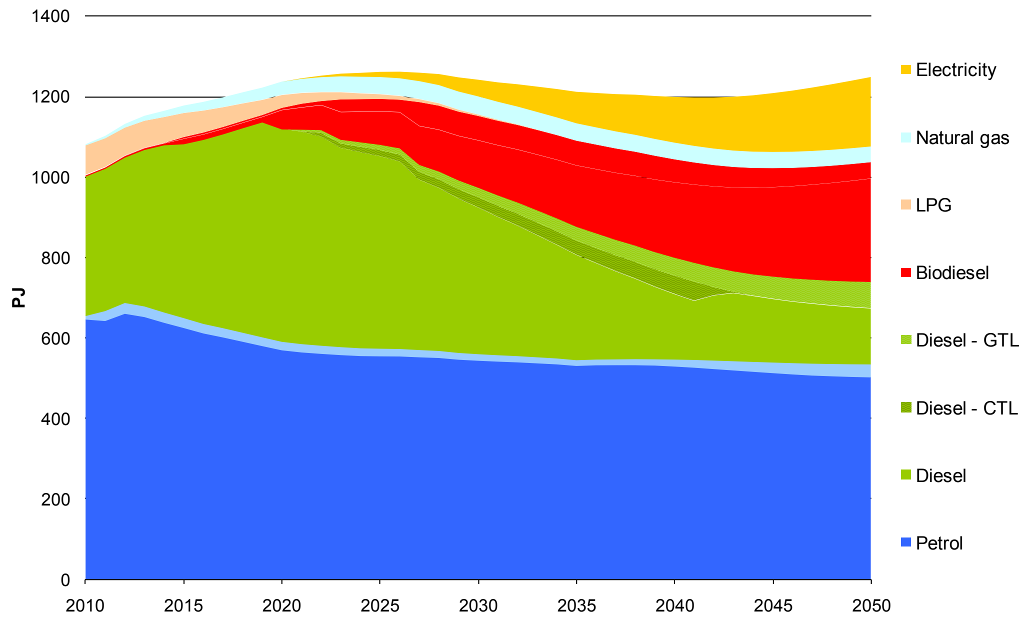

Figure 4-41: Road transport fuel consumption by fuel, Low oil/Medium-price sensitivity

In terms of vehicle engine technology, the Low oil price sensitivity leads to delayed uptake of hybrid and electric vehicles compared to the Medium global action and Medium-price scenarios leading to slightly lower uptake in the long run (Figure 4-42 and Figure 4-43).

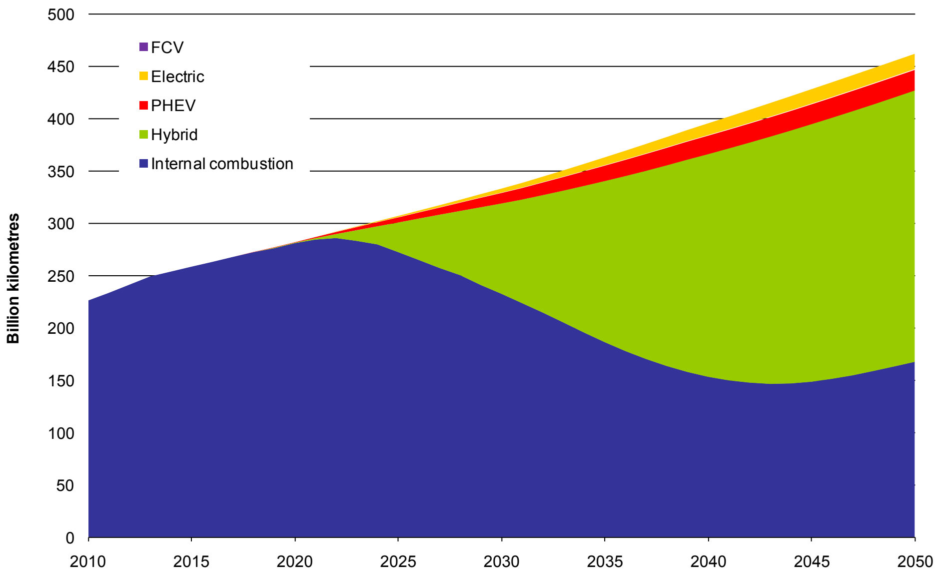

Figure 4-42: Engine type in road kilometres travelled, Low oil price/Medium global action sensitivity

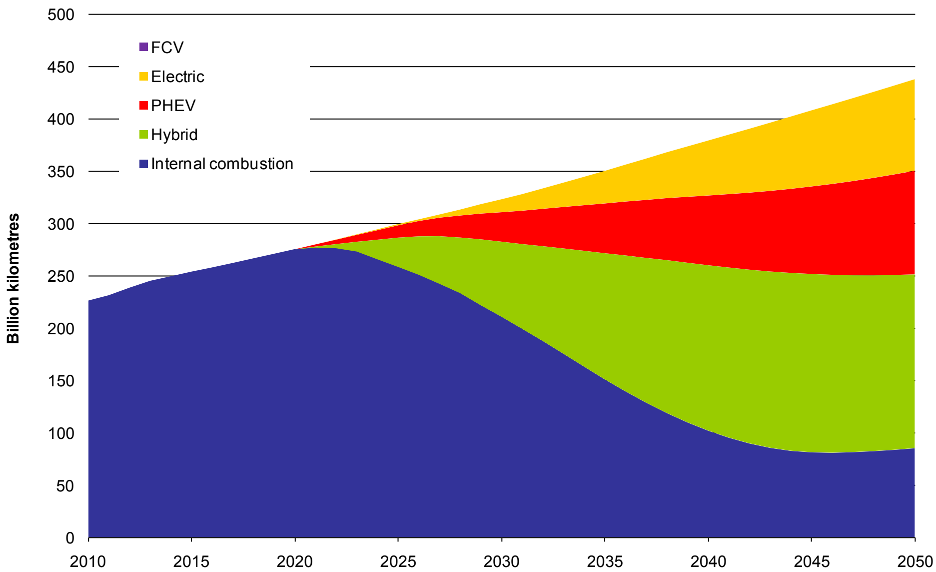

Figure 4-43: Engine type in road kilometres travelled, Low oil price/Medium-price sensitivity

Comparison of greenhouse gas emissions in Figure 4-44 reveals that the lower oil price has no impact within the next decade and contributes only to inertia in the current fuel mix rather than motivating any significant difference. However, beyond 2020 the effect of the low oil price can be observed. Fewer diesel vehicles in the fleet and slower adoption of hybrid and electric vehicles lead jointly to emission paths that are up to 2.7 $MtCO_2e$ per annum higher than in Medium global action and 5.4 $MtCO_2e$ per annum higher than in the Medium-price sensitivity. These differences in Low oil sensitivity greenhouse gas emissions narrows over time as adoption rates catch-up.

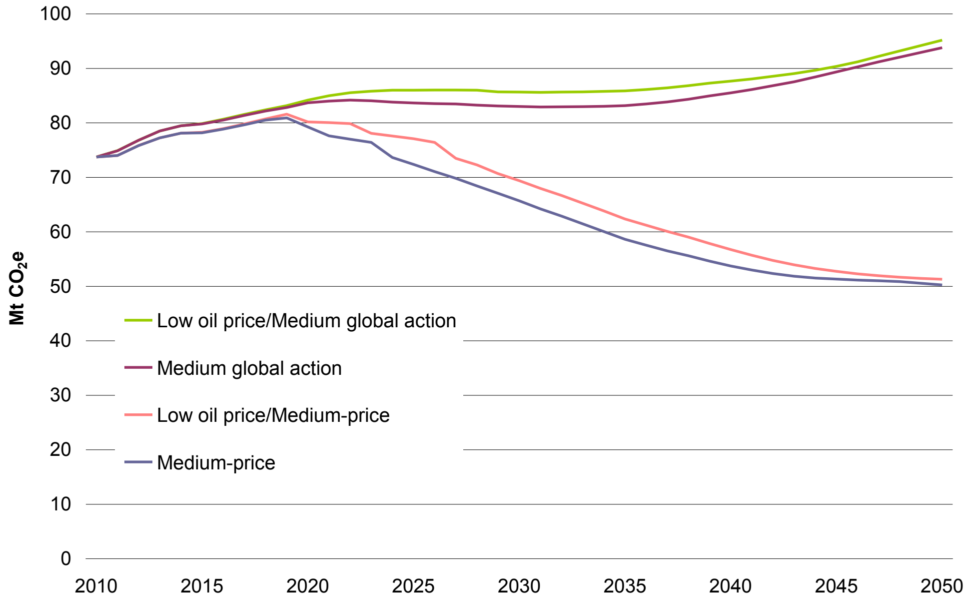

Figure 4-44: Road transport greenhouse gas emissions by fuel, Low oil price sensitivity

5. DISCUSSION OF DIVERGENCE IN RESULTS FROM AUSTRALIA'S LOW POLLUTION FUTURE

There are differences in the modelling results here compared to those in the *Australia's Low Pollution Future* report (ALPF) which used the same road transport model. This section discusses the drivers for those differences. Oil prices are one major difference, having a stronger rising trend here than those in ALPF. However, that alone does not explain the differences.

The modelling presented in this report generally projects a shift in the road transport fuel mix to diesel, biofuels, electricity, synthetic diesel (from gas and coal) and natural gas (mainly LNG in trucking).

In the period to 2030, the consumption of petroleum diesel is generally lower here than in ALPF as this report recognises structural factors in global markets that will afford diesel a sustained premium over petrol.

Electricity use as a transport fuel is also higher here than in ALPF. Both modelling exercises assumed hybrid and electric vehicles would reduce in cost over time. However, the starting prices here for electric, hybrid and plug-in hybrid electric vehicles are lower than in ALPF. These were updated based on new studies in the literature and vehicles available in the market (see Appendix A for details).

LNG truck vehicle cost assumptions are not significantly different from ALPF. As a consequence, the uptake of LNG trucks is fairly similar to ALPF, except that LNG use persists through the projection period rather than fading away. This appears to be as a result of the different gas and oil profiles used between the two modelling exercises. In ALPF the oil price fell from 2008 highs while the gas price continued to rise (so LNG lost competitiveness). However, in the current modelling both gas and oil prices rise and then flatten together (maintaining LNG competitiveness).

Biofuel uptake is higher here than in ALPF. This is because greater volumes of suitable biomass resources have been identified (in addition to higher oil prices making them more attractive). For resources estimates, ALPF relied particularly upon *Biofuels in Australia - issues and prospects*. However, this report relies mainly on newer CSIRO research by Farine et al. (forthcoming).

Farine et al. (forthcoming) updates data on the sustainable volumes of several feedstocks and adds some feedstocks, such as algae and pongamia, that were not previously included. Both of these new feedstocks produce bio-oils more suited to biodiesel than ethanol production. Hence we see here greater biodiesel use than in ALPF.

In addition to these feedstock volume updates, new data on the costs of biofuel feedstock production, refining and transport has also become available (see Appendix A for more details).

Finally, a more sophisticated structure to represent the supply of fuel from lignocellulosic biomass has been implemented in the model whereby, if the refining pathway allows, biomass can be used to produce either ethanol or biodiesel. In earlier versions, all lignocellulose was destined to make ethanol only.

A general consequence of the changes in the model together with higher oil price assumptions is that the range of projected greenhouse gas abatement options in the road transport sector is broader here than in ALPF.

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6. APPENDIX A: ESM STRUCTURE AND KEY DATA INPUTS

6.1.1 ESM model structure

Energy Sector Model (ESM) is solved as a linear program where the objective function to be maximised is welfare which is calculated as the discounted sum of consumer and producer surplus over time. The sum of consumer and producer surplus is calculated as the integral of the demand functions minus the integral of the supply functions, each of which are disaggregated into many components across the electricity and transport markets. The objective function is maximised subject to constraints that control for the physical limitations of fuel resources, the stock of electricity plant and transport vehicles, greenhouse gas emissions as prescribed by legislation, and various market and technology specific constraints such as the need to maintain a minimum number of peaking plants to meet rapid changes in the electricity load. The main components of ESM include:

- Coverage of all States and the Northern Territory (Australian Capital Territory is modelled as part of NSW)
- Nine road transport modes: small, medium and heavy passenger cars; small, medium and heavy commercial vehicles; rigid trucks; articulated trucks and buses
- Five engine types: internal combustion; hybrid electric/internal combustion; hybrid plug-in electric/internal combustion; fully electric and fuel cell
- Thirteen road transport fuels: petrol; diesel; liquefied petroleum gas (LPG); natural gas (compressed (CNG) or liquefied (LNG)); petrol with 10 per cent ethanol blend; diesel with 20 per cent biodiesel blend; ethanol and biodiesel at high concentrations; biomass to liquids diesel; gas to liquids diesel; coal to liquids diesel with upstream CO_2 capture; hydrogen (from renewables) and electricity
- Seventeen centralised generation (CG) electricity plant types: black coal pulverised fuel; black coal integrated gasification combined cycle (IGCC); black coal with CO_2 capture and sequestration (CCS) (90 per cent capture rate); brown coal pulverised fuel; brown coal IGCC; brown coal with CCS (90 per cent capture rate); natural gas combined cycle; natural gas peaking plant; natural gas with CCS (90 per cent capture rate); biomass; hydro; wind; solar thermal; hot fractured rocks (geothermal), wave, ocean current and nuclear
- Seventeen distributed generation (DG) electricity plant types: internal combustion diesel; internal combustion gas; gas turbine; gas micro turbine; gas combined heat and power (CHP); gas micro turbine CHP; gas micro turbine with combined cooling, heat and power (CCHP); gas reciprocating engine CCHP; gas reciprocating engine CHP; solar photovoltaic; biomass CHP; biomass steam; biogas reciprocating engine; wind; natural gas fuel cell and hydrogen fuel cell
- Trade in electricity between National Electricity Market (NEM) regions
- All vehicles and centralised electricity generation plants are assigned a vintage based on when they were first purchased or installed in annual increments

- Four electricity end use sectors: industrial; commercial & services; rural and residential
- Time is represented in annual frequency (2006, 2007, …, 2050).

All technologies are assessed on the basis of their relative costs subject to constraints such as the turnover of capital stock, existing or new policies such as subsidies and taxes. The model aims to mirror real world investment decisions by simultaneously taking into account:

- The requirement to earn a reasonable return on investment over the life of a plant or vehicle
- That the actions of one investor or user affects the financial viability of all other investors or users simultaneously and dynamically
- That consumers react to price signals (price elastic demand)
- That the consumption of energy resources by one user affects the price and availability of that resource for other users, and the overall cost of energy and transport services, and
- Energy and transport market policies and regulations.

The model projects uptake on the basis of cost competitiveness but at the same time takes into account constraints on the operation of energy and transport markets, current excise and mandated fuel mix legislation, GHG emission limits, existing plant and vehicle stock in each State, and lead times in the availability of new vehicles or plant. It does not take into account issues such as community acceptance of technologies but these can be controlled by imposing various scenario assumptions which constrain the solution to user provided limits.

6.1.2 ESM model outputs

For given time paths of the exogenous (or input) variables that define the economic environment, ESM determines the time paths of the endogenous (output) variables. Key output variables include:

- Fuel, engine, and electricity generation technology uptake
- Fuel consumption
- Price of fuels
- GHG and criteria air pollutant emissions
- Wholesale and retail electricity prices
- Demand for transport and electricity services.

Some of these outputs can also be defined as fixed inputs depending upon the design of the scenario.

The endogenous variables are determined using demand and production relationships, commodity balance definitions and assumptions of competitive markets at each time step for fuels, electricity and transport services, and over time for assets such as vehicles and plant capacities. With respect to asset markets, the assumption is used that market participants know future outcomes of their joint actions over the entire time horizon of the model.

6.1.3 Limitations of ESM

The suggested modelling approach suffers from two major limitations which are discussed below.

The first is that it includes many assumptions for parameters that are in reality uncertain and in some cases evolving rapidly. Parameters of most concern include, for example, possible breakthroughs in so called ―second generation” biofuel production technologies and the unknown quality and cost of future offerings of fully and partially electrified vehicles. These limitations are only partially addressed by scenario or sensitivity analysis.

A second major limitation is that ESM only takes account of cost as the major determining factor in technology and fuel uptake. Therefore, it cannot capture the behaviour of so-called ―first adopters” who take up new technology before it has reached a competitive price point. For example, most consumers of hybrid electric vehicles today could be considered ―first adopters”. Their purchase cannot be justified on economic grounds since the additional cost of such vehicles is not offset by fuel savings in any reasonable period of time (relative to the cost of borrowing). Nevertheless, hybrid electric vehicles are purchased and such purchasers may be motivated by a variety of factors including a strong interest in new technology, the desire to reduce emissions or status. As a result of this limitation, ESM‘s projections of the initial technology uptake for new technologies could be considered conservative.

However, another factor which ESM overlooks is community acceptance and this limitation might lead ESM to overestimate the rate of uptake of some fuels and technologies. For example, greater use of gaseous fuels such as LPG and the introduction of electricity as a transport fuel might be resisted by the Australian community which has predominantly used liquid fuels for transport over the past century. By design, ESM only considers whether the choice is economically viable.

As a result of these limitations, the technology and fuel uptake projections that will be estimated need to be interpreted with caution. In reality, consumers will consider a variety factors in fuel and vehicle purchasing decisions. However, it is the view of the authors that the projections are nonetheless instructive in that they indicate the point at which the various technology or fuel options should become widely attractive to all consumers.

6.2 Road vehicle type configuration

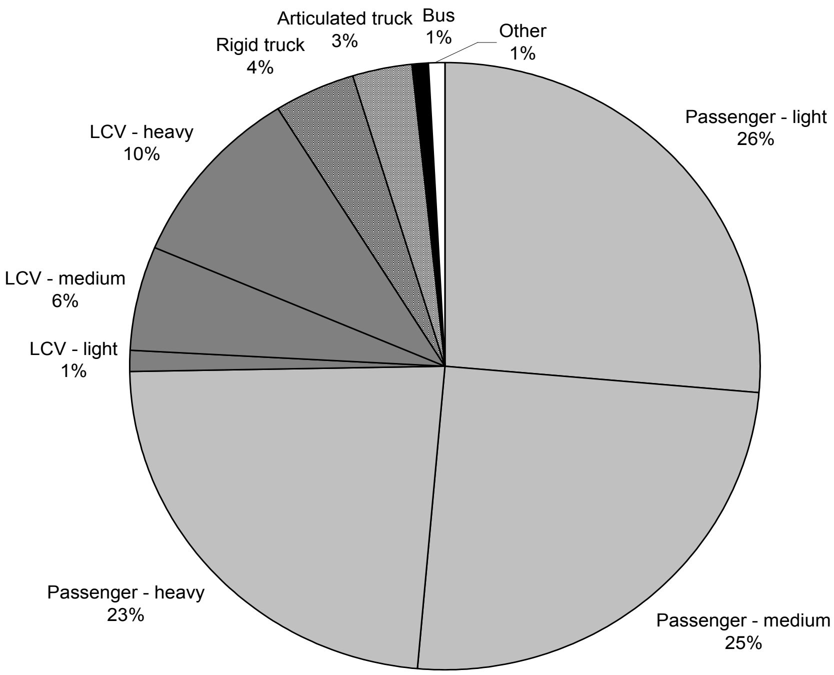
An important consideration in the transport model is how to represent the vehicle type combinations that are of interest. In theory, one could construct a model of the Australian road transport sector which included every make of existing vehicle type and possible future types. In practice, modellers will always seek to reduce the size of the technology set in order to make the model manageable in terms of data, model structure and mathematical solution speed and reliability.

For road transport, the proposed vehicle aggregation is as follows. Passenger and light commercial vehicles are represented in three weight categories:

- Light/small: less than 1200 kg
- Medium: 1200 to 1500 kg
- Heavy/large: 1500 to 3000 kg.

The remaining vehicle types are rigid trucks, articulated trucks and buses. Motor cycles and campervans are not specifically modelled but are accounted for as a constant in the emission profile.

Fleet data for Australia was sourced from the *Australian Bureau of Statistics* and the vehicle weight categories based on data therein.



Source: ABS (2007).

Figure 6-1: Current share of kilometres travelled within the Australian road transport task by vehicle type, 2006

6.3 Road fuel coverage

Within the current version of ESM, the road transport fuel options are:

- Petrol – aggregating unleaded, lead replacement and premium (PET)
- Petrol with 10 per cent ethanol (E10)
- Ethanol blend with up to 85 per cent ethanol and 15 per cent petrol (E85)[1]
- Diesel (DSL)
- Diesel with 20 per cent biodiesel blend (B20)
- 100 per cent biodiesel (B100)
- Liquefied petroleum gas (LPG)
- Compressed natural gas (CNG)
- Liquefied natural gas (LNG)
- Hydrogen produced from renewables (H_2)
- Biomass to liquids (BTL) diesel
- Gas to liquids (GTL) diesel
- Coal to liquids (CTL) diesel with upstream CO_2 capture and storage
- Electricity (ELE).

This is obviously not a complete list of possible fuels but covers those that are generally of greatest interest.

More categories of hydrogen production might be desirable. However, given the greatest cost associated with hydrogen is not the fuel but the cost of the storage and engine system, including additional cheaper hydrogen sources will make little difference in the modelling.

Compressed natural gas (CNG) is assumed to be used in all natural gas vehicles except for articulated trucks which use Liquefied natural gas (LNG).

Table 1 maps the allowable road mode and fuel combinations for road transport in ESM.

[1] Consistent with experience overseas, there is expected to be seasonal variation in the ethanol content as ambient temperature affects performance of the fuel. This translates to lower ethanol content during the winter months.

Table 1: Allowable road mode and fuel combinations

	PASL	PASM	PASH	LCVL	LCVM	LCVH	RGT	BUS	ART
PET	x	x	x	x	x	x			
E10	x	x	x	x	x	x			
E85	x	x	x	x	x	x			
DSL	x	x	x	x	x	x	x	x	x
B20	x	x	x	x	x	x	x	x	x
B95	x	x	x	x	x	x	x	x	x
LPG	x	x	x	x	x	x			
CNG	x	x	x	x	x	x	x	x	
LNG									x
H_2	x	x	x	x	x	x	x	x	
GTL	X	x	x	x	x	x	x	x	x
CTL	X	x	x	x	x	x	x	x	x
ELE	X			x			x	x	

Notes: PASL: light/small passenger vehicles; PASM: medium passenger vehicles; PASH: heavy/large passenger vehicles; LCVL: light/small commercial vehicles; LCVM: medium commercial vehicles; LCVH: heavy/large commercial vehicles; RGT: rigid trucks; BUS: buses; ART: articulated trucks.

6.4 Road engine type configurations

The engine configurations allowed for road transport are:

- Internal combustion (ICE)
- Mild hybrid internal combustion-electric (HYB)
- Plug-in hybrid electric (PHEV)

- Full (100 percent) electric (EV)
- Fuel cell (FCV).

Fully electric vehicles (EVs) were deemed to be only available in the light/small passenger and light/small commercial vehicle types due to range and power limitations. Conversely, hybrids were allowed in all other categories. Medium and heavy/large passenger and light/small commercial vehicle categories are available as PHEVs (internal combustion engine and electric motor on board capable of driving for extended periods) as are rigid trucks and buses. Articulated trucks were limited to mild hybridisation (for example, engine stop and fast start capability). The fuel efficiency section outlines what this means in performance terms

FCVs use fuel cells to convert the chemical energy contained in hydrogen into electricity, which is used to power an electric motor that drives the wheels and support other vehicle functions. FCVs are currently available in some jurisdictions overseas in limited numbers.

As fuel cell systems improve and FCVs are proven technically, the refuelling and fuel infrastructure issues are likely to become the main barriers to commercialisation. Fuel cell system costs have declined but are still very expensive compared to conventional ICE vehicles (see Section 6.5.1).

Table 2 maps the allowable road mode and engine combinations for road transport in ESM.

Table 2: Allowable road mode and engine combinations

	PASL	PASM	PASH	LCVL	LCVM	LCVH	RGT	BUS	ART
ICE	x	x	x	x	x	x	x	X	x
HYB		x	x		x	x	x	X	x
PHEV		x	x		x	x	x	X	
EV	x			x			x	X	
FCV	x	x	x	x	x	x	x	X	

6.5 Road transport costs

One of the key functions of ESM is to determine the uptake of fuel and engine technologies. These can be imposed but the default process is for the model to choose the least cost response to whatever drivers are in force (such as carbon pricing). In order for the model to give a plausible answer it must, as a minimum, be provided with data to compare the relative economic merits of the vehicles that would be under consideration by the consumer (or investor).

6.5.1 Vehicle costs

Table 3 sets out the major categories of non-fuel costs and sources of data for them. Basic vehicle costs are representative of the median vehicle in their vehicle category. There is a wide margin of error. However, it cannot be easily avoided given the need for aggregation (see previous section). Maintenance costs are calculated via bottom up analysis of the minimum maintenance expenditure required to renew registration of the vehicle (e.g. tyre change every two years, minimal oil and battery replacement). In addition to regular maintenance, major part replacement is assumed to become part of the maintenance cost of older vehicles (> 5 years).

For some alternative fuels, there is little or no information available about additional vehicle requirements and costs for the alternative fuel to be incorporated. In these cases, estimates have been made based on the ratio of costs in a closely relevant vehicle category.

In constructing non-fuel costs, the data has relied on a wide variety of predominantly web based sources and may be poor in some cases. To test the validity of the data it is compared with the NRMA's 2011 *Private Whole of Life Fixed Vehicle Operating Costs* report.

Table 3: Non-fuel cost categories in total road travel cost

Non-fuel cost category	Data source
Basic vehicle cost	ICE (Passenger and light commercial): NRMA *Open Road*. ICE (Trucks and buses): Manufacturers websites. EVs/PHEVs: IEA (2009b); Electrification Coalition (2009). FCVs: IEA (2009b); ANL (2009).
On-costs above basic vehicle cost to accommodate alternative fuel	Various manufacturer websites
Insurance – third party and comprehensive	Insurance companies (e.g. AAMI, NRMA)
Registration	State government transport authority/department websites
Maintenance	Web sources on tyres, oil, batteries and servicing

The comparison is shown in Table 4. To simplify the comparison we have used the same fuel costs as quoted in the NRMA report which was an unleaded petrol price of 125.8c/L.

Table 4: Comparison of whole of life transport cost estimates for Australian petrol passenger vehicles (c/km)

Category	NRMA estimate	CSIRO estimate
Small/light	39.3	41.9
Medium	60.5	60.6
Large/heavy	79.7	76.3

NRMA has based the above estimates on a small car of less than $40,000, a medium car of less than $60,000 and large car of less than $70,000. The CSIRO estimates differ in absolute terms mainly in the light and large vehicle categories but are of similar magnitude. Our estimates represent an average of vehicle costs in defined weight categories.

Costs of rigid trucks are 95-140c/km. Costs for articulated trucks are 100-180c/km. Costs for buses are 175-250c/km. There are fewer references for comparison of these costs.

It is assumed that all internal combustion vehicle purchase costs and all other non-fuel costs rise with the level of inflation and therefore remain constant in real terms. This assumption is justified on the basis that increased costs associated with fuel efficiency improvements of 15-25 percent are assumed to be offset by reductions in costs elsewhere on the vehicle.

For other vehicles, notably hybrid vehicles (HVs), plug-in hybrid electric vehicles (PHEVs), fully-electric vehicles (EVs) and fuel cell vehicles (FCVs), costs are assumed to fall. This is discussed in Section 6.6.

6.6 Treatment of technological change in the transport sector

There are significant uncertainties in terms of the timing and extent of the assumed reductions in the costs of non-ICE vehicles. Achieving these cost reductions relies on adequate supply of minerals and other raw materials, successful further development of battery and other technologies and realisation of global production economies of scale.

The cost assumptions for three points in time, 2010, 2030 and 2050 are shown in Table 5. The assumption regarding hybrid vehicles (HVs) is that over two decades mild hybridisation of vehicles will become standard and will not involve significant additional cost.

Similar to HVs, PHEVs are expected to always cost a premium over a standard internal combustion vehicle in the same vehicle category. Starting from a relative cost gap of around $14,000 to $18,000 for passenger and LCVs, costs are expected to narrow to less than an additional $3,000 by 2030.

For light EVs the price gap is around $22,000 in 2010 meaning that the vehicles are around 2.5 times more expensive than an equivalent ICE. Furthermore, global deployment is limited and in

Australia only retrofitted EVs are available. Therefore, we assume no improvement in this gap until mass production built for purpose vehicles are available. This is assumed to occur during the next two decades. By 2030, the price gap has halved and reaches around $4,000 by 2050.

For FCVs, the vehicle cost in 2010 is notional as no FCVs are currently available in Australia, and the estimate is based on a relative cost to an ICE reported in ANL (2009). Although the costs of FCVs decline over time, the rate of decline to 2030 is significantly less than that for EV/PHEVs. FCVs face greater technical hurdles than EV/PHEVs including a lack of fuel distribution and production infrastructure. Accordingly, the likelihood of FCVs emerging as a future low carbon option is less evident than that of EV/PHEVs (IEA, 2009).

Table 5: Assumed current and future representative vehicle costs, $,000

	Passenger vehicles			LCVs			Trucks		Bus
	Light	**Medium**	**Heavy**	**Light**	**Medium**	**Heavy**	**Rigid**	**Art'd**	
	2010								
ICE*	14	25	41	14	25	41	61	300	180
HYB	N/A	28	44	N/A	28	44	100	370	260
PHEV	N/A	39	59	N/A	39	59	107	N/A	271
EV	36	N/A	N/A	36	N/A	N/A	121	N/A	300
FCV	51	85	140	51	85	140	209	N/A	616
	2030								
ICE*	14	25	41	14	25	41	61	300	180
HYB	N/A	26	42	N/A	26	42	63	305	185
PHEV	N/A	27	44	N/A	27	44	67	N/A	193
EV	20	N/A	N/A	20	N/A	N/A	77	N/A	212
FCV	30	52	84	30	52	84	124	N/A	362
	2050								
ICE*	14	25	41	14	25	41	61	300	180
HYB	N/A	25	41	N/A	N/A	41	61	300	180
PHEV	N/A	26	43	N/A	26	43	67	N/A	192
EV	18	N/A	N/A	18	N/A	N/A	73	N/A	204
FCV	22	40	50	22	40	50	98	N/A	288

* The standard internal combustion engine (ICE) vehicle is considered to be a representative base vehicle for the category and weight class given.

Sources: NRMA; IEA (2009); Electrification Coalition (2009); ANL (2009).

6.7 Road fuel costs

The oil and natural gas price assumed in each scenario determines the changes in retail prices for the fossil fuel categories (petrol, diesel, LPG) with some differences according to relative energy content.

The electricity price is also set externally by an electricity model which forms part of the modelling framework.

6.7.1 Synthetic fuels

The IEA (2008) estimates the production cost of coal to liquids (CTL) and gas to liquids (GTL) liquid fuels in the range of USD60-110/bbl and USD40-110/bbl, respectively. The cost of CO_2 capture and storage for CTL diesel is assumed to be \$20/tCO_2e. Both CTL diesel and GTL diesel are assumed to be available only after 2020.

6.7.2 First generation road biofuels

For first generation biofuels, biodiesel and ethanol, the cost is based on the volume of demand as per the cost-quantity curves in Figure 6-3. These curves are derived from O'Connell et al. (2007) and have been since updated to take account of recent price movements. Due to competition with the food production industry, it is assumed that only 5 per cent of this volume is available over the next decade for most food feedstocks. The restriction to 5% availability excludes used cooking oil and tallow not exported, all of which is assumed to be available for biodiesel.

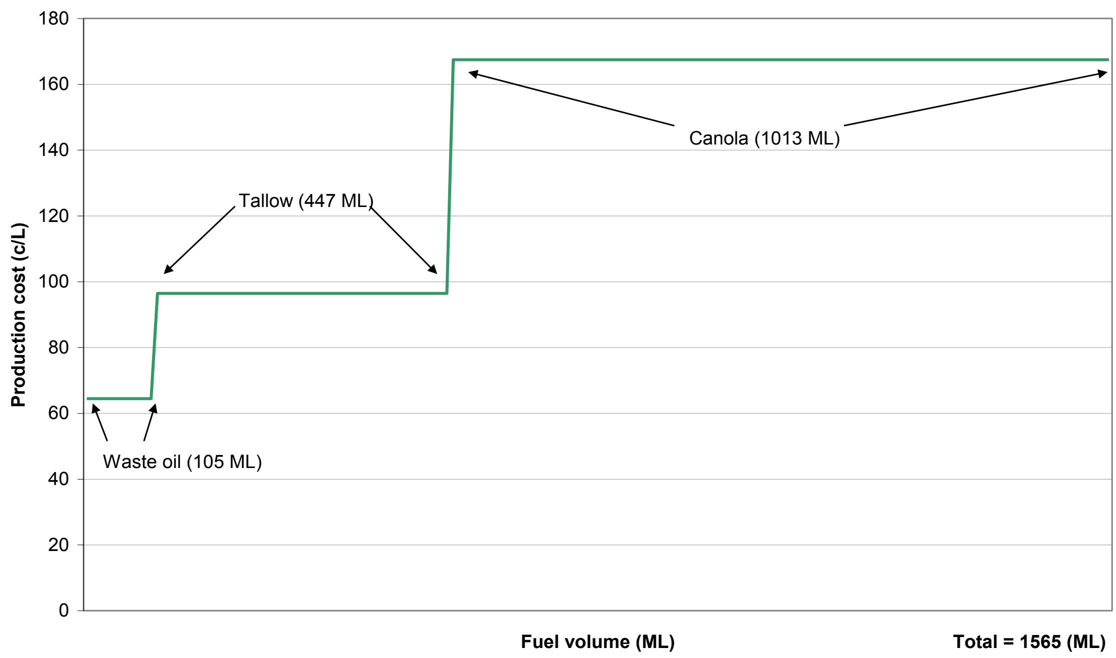


Figure 6-2: First generation ethanol cost-quantity curve

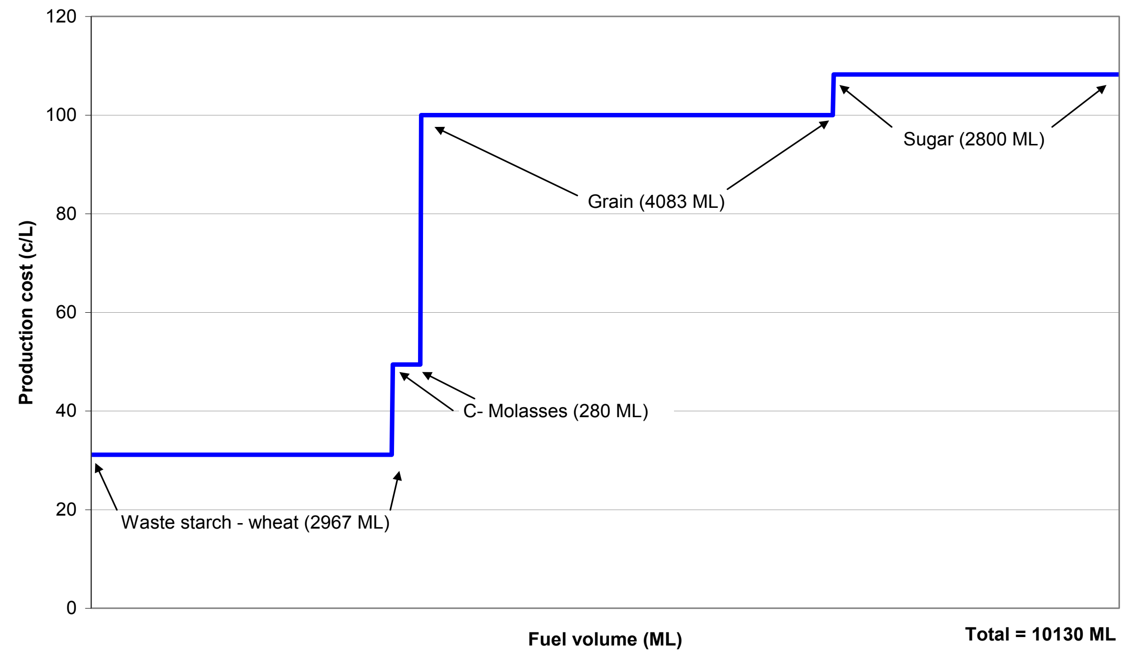


Figure 6-3: First generation biodiesel cost-quantity curve

It should be noted that the timing of the availability of second-generation biofuel is subject to considerable uncertainty.

6.7.3 Second generation road biofuels

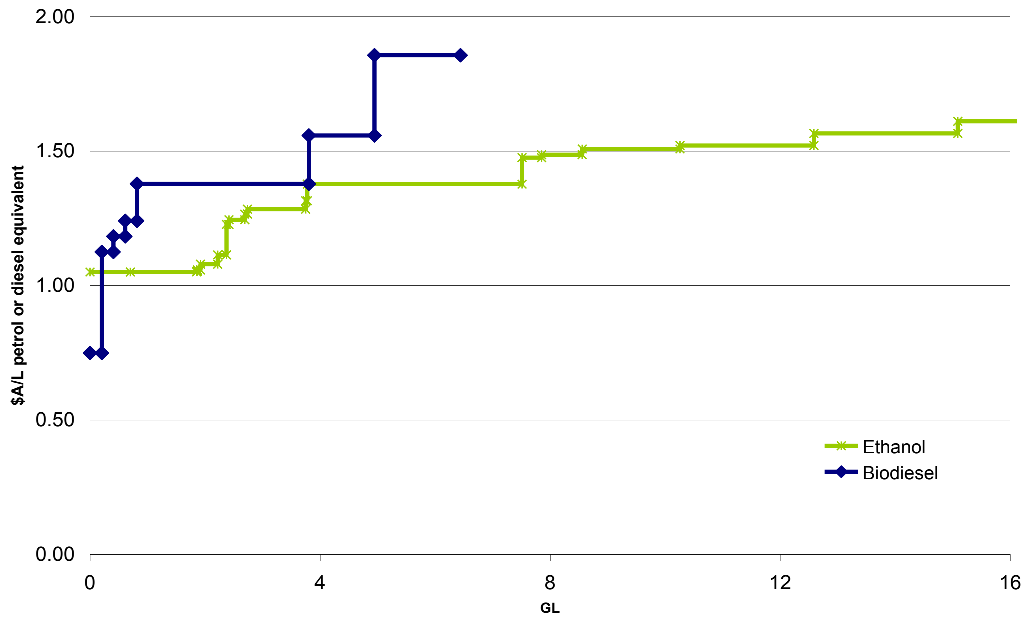


Figure 6-4: Cost curve for second generation road biofuels

Figure 6-4 and Figure 6-5 shows the cost curve as a function of biomass availability and components costs for the production of second generation road biofuels respectively. The charts use second generation biofuel supply data based on detailed feedstock assessment (Farine et al. (forthcoming).

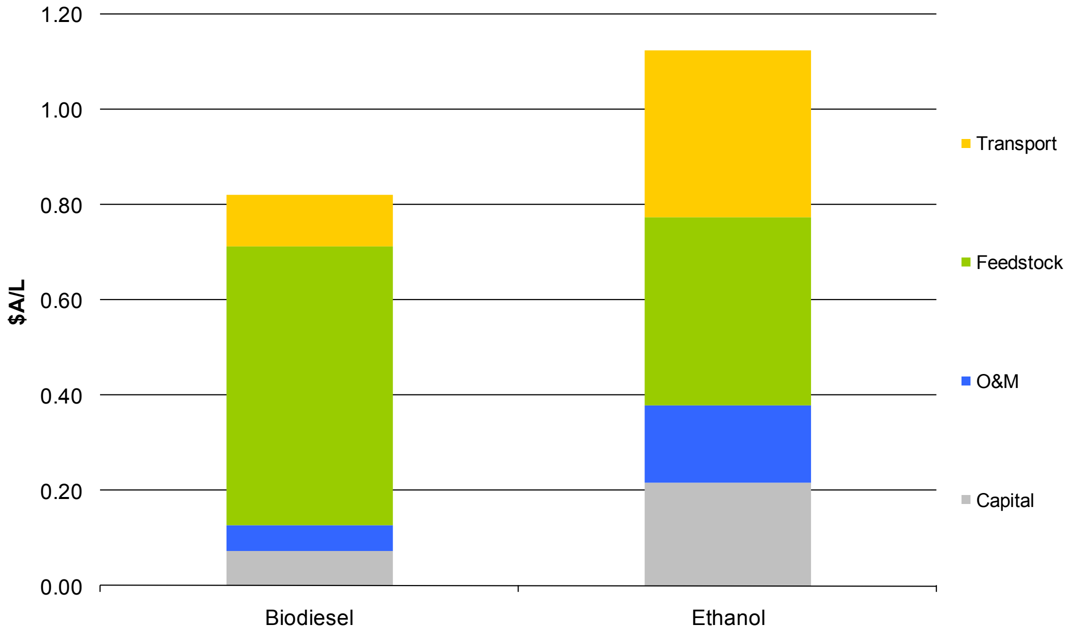


Figure 6-5: Component costs for second generation production of ethanol and biodiesel

6.8 Road fuel efficiency

The efficiencies of fuels not currently in use and therefore not reported in ABS (2007) were calculated based on the relative energy content which is shown in Table 6. In some cases there is considerable uncertainty since energy content can vary due to different feedstocks, particularly for biofuels.

Table 6: Properties of selected fuels (/L, or /m^3 for CNG and H_2)

	LHV (MJ/kg)	Density (kg/L or kg/m^3)	LHV (MJ/L or MJ/m^3)
Petrol	42.7	0.75	32.0
Diesel	42.5	0.84	35.7
LPG	46.1	0.53	24.4
CNG	45.1	0.78	35.2
LNG	49.3	0.42	20.4
B100	40.2	0.84	35.3
B20	42.0	0.84	35.3
E85	29.2	0.78	22.8
E10	41.1	0.75	30.8
H_2	120.0	0.09	10.8
GTL diesel	40.0	0.84	33.6
CTL diesel	40.0	0.84	33.6

Note: The Lower Heating Value (LHV) is used in deference to Higher Heating Value (HHV) as the latent enthalpy of vaporisation for water vapour exhaust gas is not recovered in useful work.

Source: Graham et al. (2008)

The energy content of reported fuels was used to determine generic energy consumptions for Spark Ignition (gasoline) or Compression Ignition (diesel) internal combustion engines. Each alternative fuel was associated with the energy consumption of either the SI or CI combustion process, and alternative fuel efficiencies were then determined according to the properties of the individual fuel.

The assumed relationship between fuel type and combustion process is presented in Table 7. For light duty vehicles, buses and rigid trucks, all variants of diesel fuel were assumed applicable to CI engines, the remainder to SI engines. For articulated trucks it was assumed that all fuels with the exception of gasoline and E10 were applicable to CI engines. This is because performance requirements in this sector determine that CI diesel is dominant, and alternative fuel programs accordingly rely on this architecture.

Table 7: Combustion process according to fuel

	Petrol	Diesel	LPG	CNG	LNG	B100	B20	E85	E10	H_2	GTL	CTL
Passenger Cars												
Light	SI	CI	SI	SI	NA	CI	CI	SI	SI	SI	CI	CI
Medium	SI	CI	SI	SI	NA	CI	CI	SI	SI	SI	CI	CI
Heavy	SI	CI	SI	SI	NA	CI	CI	SI	SI	SI	CI	CI
LCVs												
Light	SI	CI	SI	SI	NA	CI	CI	SI	SI	SI	CI	CI
Medium	SI	CI	SI	SI	NA	CI	CI	SI	SI	SI	CI	CI
Heavy	SI	CI	SI	SI	NA	CI	CI	SI	SI	SI	CI	CI
Trucks & Buses												
Rigid	SI	CI	SI	SI	NA	CI	CI	SI	SI	SI	CI	CI
Art'd	SI	CI	CI	NA	CI	CI	CI	CI	SI	CI	CI	CI
Buses	SI	CI	SI	SI	NA	CI	CI	SI	SI	SI	CI	CI

Note: Articulated trucks using LNG

In some instances it is recognised that alternative fuel characteristics will adversely or beneficially affect the combustion process and in such cases the energy consumption is subjected to a correction factor. The correction factor is adjusted over time, as both the properties of alternative fuels and the deployment of appropriate engine technology are assumed to evolve.

6.8.1 Greenhouse gas emission factors

For the main fuels in use today, direct and fugitive emission factors have been calculated from values provided in *National Greenhouse Accounts (NGA) Factors* (DCC, 2009) with some adjustment for upstream or indirect emissions. For less common fuels CSIRO internal data have been used. The full fuel cycle emission factors (direct plus indirect emissions) gives the quantity of emissions released per unit of energy for the entire fuel production and consumption chain.

The full fuel cycle emission factors in grams per kilometre for road vehicles are shown in Table 8. It can be expected that estimates of upstream emission factors will change over time. For example, the science of estimating the impact of extracting fuels from biomass is still being developed. The emission factors for biofuels in Table 8 are drawn from DCC (2008). Furthermore, the conversion process for coal and gas to liquids are still being actively improved. Finally, some fossil fuels, such as oil, may become more difficult to extract, therefore requiring more use of energy upstream. Ideally these changes should be incorporated. However, currently there is not enough reliable data to do so. Downstream or direct emission factors can be expected to improve because of improvements in fuel efficiency - this is incorporated in the modelling.

Table 8: Full fuel cycle CO_2-e emission factors for each fuel and road vehicle category (g/km)

	Passenger Vehicle			LCVs			Trucks		Bus
	Light	**Med.**	**Heavy**	**Light**	**Med.**	**Heavy**	**Rigid**	**Art'd**	
Petrol	215	240	329	245	274	375	NA	NA	NA
Diesel	175	196	268	200	223	306	800	1493	738
LPG	195	218	298	222	248	340	836	NA	NA
CNG	203	227	311	232	259	355	873	NA	806
LNG	NA	NA	NA	NA	NA	NA	NA	1426	NA
B100	21	23	32	25	26	36	104	198	101
B20	131	147	201	157	168	229	664	1183	609
E85	170	190	260	194	217	296	NA	NA	NA
E10	213	238	326	242	271	372	NA	NA	NA
BTL Diesel	42	46	64	50	52	72	208	396	202
GTL Diesel	175	196	268	200	223	306	800	1493	738
CTL Diesel	199	222	305	226	254	347	908	1694	837
Hydrogen (ren.)	0	0	0	0	0	0	0	0	0

Note: Electricity fuel is not assigned an emission factor because its emissions are determined by the emission intensity of electricity generation which varies by scenario..

Source: DCC (2008); Graham et al. (2008).

6.8.2 Efficiency improvements over time

The change in fuel efficiency over time is based on judgement of the balance of two competing factors. The first is improvements that have already been, or are likely to be, achieved internationally where fuel excise rates are several times those in Australia. The second is the historical lack of improvement in fuel efficiency owing to:

- Greater non-propulsion use of energy within the vehicle, for amenities such as air conditioning (itself a function of growing wealth and consumer expectations)
- The trend towards large vehicles within some weight categories (particularly 4WDs/SUVs in the large vehicle category), and

- The robustness of household expenditure to fuel price changes owing to the small proposition of fuel costs in the household budget (amounting to no more than 2-3 per cent of average adult annual income).

It is assumed that vehicles equipped with SI engines will improve in efficiency by 25 per cent and CI engines by 14 per cent from 2006 to 2050, independently of changes related to fuel type and hybrid drivetrain. These improvements are proposed to arise from increased efficiency of vehicle and engine technology in new vehicles, and the extent to which the existing fleet is modified by the addition of new vehicles.

Whilst equivalent vehicle improvements are assumed for both SI and CI vehicles, it is proposed that there is significantly greater scope to enhance the operating efficiency of the SI engine and that by 2050 the efficiencies of SI and CI engines will converge, with differentiation according only to the combustion characteristics of alternative fuel types. The efficiency of the SI engine is proposed to be increased through the following:

- Optimisation of engine gas exchange processes and reduction of pumping work, through the deployment of advanced valvetrains

- Increase in compression ratio towards optimum values, enabled by the use of direct injection and advanced valvetrains

- Reduction in engine friction and the operation of engines in regions of highest efficiency, enabled by down-sizing, in turn achieved by higher specific output with boosting, and

- Operation at extended lean and dilute limits, facilitated by advanced combustion processes, and enabled in part by the availability of lean emission after treatment and low-sulfur fuels.

For the REF scenario, it is implicitly assumed that all improvements that are technically feasible, but costly to introduce in the near future, will come on line slowly toward 2050, once the costs have been reduced sufficiently to make them competitive.

Table 9 presents assumptions about road vehicle fuel intensity by fuel type for conventional ICE vehicles.

Combined with non-engine efficiency improvements, fuel intensities for ICE‘s are assumed to decline up to 37 per cent between 2006 and 2050. Hybrid electric vehicle fuel intensity assumptions are developed based on their performance relative to ICE only vehicles.

It is assumed that the mild hybrid category has a 5 per cent improvement in fuel efficiency starting in 2006 increasing to a 30 per cent improvement by 2050 for all road categories except for articulated trucks. Articulated trucks improve to only 10 per cent better than conventional articulated trucks. Mild hybrids draw no electricity from the grid.

The assumptions for PHEVs, which do draw electricity from the grid, are more complicated. Total fuel efficiency is calculated on the basis of the percentage of time in which it uses the electric drive train. When using the ICE drivetrain it has the ICE-only efficiency for that year. When using the electric drivetrain it has the following efficiencies:

- Light passenger: not applicable
- Medium passenger: 0.22kWh/km
- Heavy passenger: 0.31kWh/km
- Rigid truck: 0.85 kWh/km
- Bus: 0.8kWh/km.

These electric drivetrain efficiencies are held constant over time on the basis that any improvements are used up to provide better amenity (passenger and luggage room, safety, comfort, performance and instruments) rather than fuel savings.

The percentage of time using electric drivetrain in total annual kilometres is assumed to be 50 per cent initially in 2006, increasing to 80 per cent by 2035 as battery technology improves and allows for greater use of the electric drivetrain. For the remainder of kilometres the ICE drivetrain is in use. As such, a weighted average of the efficiency of these drivetrains gives the average annual efficiency for any given year.

In order to calculate fuel intensities in intervening years, constant compound growth rates were derived from the two end points. For each class, the implied annual growth in fuel efficiency to 2050 thus calculated is observed to be slightly slower than that over the last 30 years (consistent with an apparent slowdown in this growth since the 1980s).

EVs are used within the categories light vehicles, rigid trucks and buses only and assumed to use the electric drivetrain 100 per cent of the time at 0.2 kWh/km, 0.85 kWh/km and 0.8 kWh/km, respectively. Again, these efficiencies are held constant over time on the basis that any improvements in electric drivetrain efficiency are used up to provide better amenity.

Note, at a residential electricity price of 15c/kWh, the cost of electricity as a fuel for light vehicles is 3c/km. However, we assume that charging takes place at off-peak rates closer to 9c/kWh resulting in a fuel cost of 1.8c/km. This is less than one fifth of 11.5c/km, the cost of fuel for a petrol vehicle in the same weight class at a petrol price of 128c/L. Note that both electricity and petrol prices will change over time depending on the scenario being modelled.

The fuel efficiency of FCVs is approximately double that of an ICE vehicle.

Table 9: Assumed fleet average fuel efficiency by engine type (L/100km), conventional vehicles

	Petrol		Diesel		LPG		CNG (m^3) & LNG (L)		B95		B20		E85		E10		H_2 (m^3/100km)		BTL/GTL/CTL diesel	
	2006	**2050**	**2006**	**2050**	**2006**	**2050**	**2006**	**2050**	**2006**	**2050**	**2006**	**2050**	**2006**	**2050**	**2006**	**2050**	**2006**	**2050**	**2006**	**2050**
Passenger Cars																				
Light	9.1	6.8	6.3	5.4	12.1	8.6	8.0	5.5	7.7	6.3	6.5	5.6	12.8	8.6	9.5	7.1	36.7	23.3	6.6	5.7
Medium	10.2	7.6	7.1	6.1	13.6	9.6	9.0	6.2	8.6	7.1	7.3	6.3	14.3	9.6	10.6	7.9	41.1	26.1	7.4	6.4
Heavy	14.0	10.4	9.7	8.3	18.6	13.2	12.3	8.5	11.8	9.7	10.0	8.6	19.6	13.2	14.5	10.8	56.3	35.7	10.1	8.7
LCVs																				
Light	10.4	7.8	7.2	6.2	13.8	9.8	9.2	6.3	8.8	7.2	7.4	6.4	14.6	9.8	10.8	8.0	41.8	26.6	7.5	6.5
Medium	11.6	8.7	8.1	7.0	15.5	11.0	10.3	7.0	9.8	8.1	8.3	7.2	16.4	11.0	12.1	9.0	46.9	29.7	8.4	7.2
Heavy	15.9	11.9	11.1	9.5	21.2	15.0	14.0	9.6	13.5	11.0	11.4	9.8	22.4	15.0	16.5	12.3	64.2	40.7	11.5	9.9
Trucks & Buses																				
Rigid	39.2	29.3	28.9	24.9	52.2	37.0	34.5	23.7	35.2	28.8	29.8	25.6	55.1	37.0	40.6	30.3	157.8	100.1	30.1	25.9
Art'd	73.1	54.6	54.0	46.4	85.2	69.7	83.4	68.3	65.7	53.8	55.6	47.8	89.9	69.6	75.8	56.6	257.6	199.4	56.2	48.4
Buses	36.2	27.0	26.7	23.0	48.1	34.1	31.9	21.9	32.5	26.6	27.5	23.6	50.8	34.1	37.5	28.0	145.6	92.4	27.8	23.9

Sources: Graham et al. (2008); BITRE and CSIRO (2008).

7. DEFAULT POLICY SETTINGS

This section briefly discusses default policy settings that will be applied in the reference scenarios, and remain active in the comparative scenarios unless otherwise dictated by the scenario definition. While comparative scenarios explore policy development in various areas, the default settings include policies that have been announced or are currently in place. City planning and infrastructure investment are implied by the assumptions in the section on transport services demand and fuel efficiency. This section outlines three additional polices. These are the cost of vehicle registration, excise rates, and the New South Wales ethanol mandate.

7.1 Vehicle registration

Most states provide vehicle registration fees on stepped scale with lower fees being for smaller vehicles. Victoria is an exception (based on postcode). Pensioners and other groups also receive rebates. Victoria provides a $100 rebate for hybrid and electric vehicles. It is assumed these policy settings remain in place and the cost of registration is maintained in real terms. Trucks and buses registration costs are set nationally and also increase with size.

7.2 Excise rates and levies

National road excise rates applying to transport fuels have recently been re-designed and are set in nominal dollar terms. Biofuels remain exempt. However, LPG and natural gas will experience a gradual phase in of excise rates based on energy content. As a result, these alternative fuels will be more costly than currently but will remain discounted relative to conventional fuels. The phase-in period is to 2015. Ethanol imports will have a protective duty of 5 percent. The effective excise rates for alternative fuels are shown in Table 10.

Table 10: Effective road excise rates for alternative fuels, 2010-2015

	LPG	Natural Gas	Biodiesel	Ethanol
	$ per litre	**$ per kilogram**	**$ per litre**	**$ per litre**
2011-12*	0.02500	0.05224	0.00000	0.00000
2012-13	0.05000	0.10448	0.00000	0.00000
2013-14	0.07500	0.15673	0.00000	0.00000
2014-15	0.10000	0.20897	0.00000	0.00000
2015-16	0.12500	0.26122	0.00000	0.00000

* LPG and natural gas rates introduced from December in 2011

It will be assumed that the level of excise remains constant in nominal terms from 2015 onwards. As a result, excise rates are assumed to decline in real terms.

7.3 New South Wales biofuel mandate

Under the *Biofuel (Ethanol Content) Act 2007,* which came into effect on 1 October 2007, primary petrol wholesalers must ensure that ethanol makes up a minimum of 2 per cent of the total volume of NSW sales. Not all fuels sold will contain ethanol but the consumer has the choice of filling up with E10 petrol (contains a blend of 10 per cent ethanol).

The *Biofuel (Ethanol Content) Amendment Act 2009*, which came into effect on 1 October 2009, does the following:

- Renames the original Act to become the *Biofuels Act 2007*
- Increases the volumetric ethanol mandate to 4% from 1 January 2010
- Further increases the ethanol mandate to 6% from 1 July 2011
- Requires all regular grade unleaded petrol to be E10 from 1 July 2012
- Establishes a volumetric biodiesel mandate of 2% (this requirement has been suspended until 1 January 2010)
- Increases the biodiesel mandate to 5% from 1 January 2012
- Amends the definition of primary wholesaler to include diesel as well as petrol wholesalers
- Applies the volumetric mandates to major retailers (those that control more than 20 service stations) as well as primary wholesalers
- Provides for sustainability standards for biofuels, and
- Provides for exemptions from the requirement for all unleaded petrol (ULP) to be E10, for marinas and small businesses suffering hardship.

The Amendment Act provides that the implementation dates may be delayed or measures may be wholly or partly suspended under certain circumstances, for example, if sufficient feedstock or production of biofuels is not available.

The New South Wales biofuels mandate is directly applied in the model as a constraint on the minimum use of biofuels in fuel consumed by vehicles in NSW.

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