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Transport Greenhouse Gas Emissions Projections 2013-2050

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Executive summary

The CSIRO was commissioned by the Department Industry, Innovation, Climate Change, Science, Research and Tertiary Education (the Department) to provide annual projections of emissions and activity for the transport sector highlighting total emissions from 2009-10 to 2049-50.

The modelling is conducted using a combination of top town approaches in the case of rail and marine transport and a partial equilibrium model covering road and aviation. The partial equilibrium model is called the Energy Sector Model (ESM) and covers the Australian energy sector. The ESM contains nine road vehicle categories including buses, trucks and passenger vehicles. The ESM was developed by CSIRO and ABARE in 2006. Since that time CSIRO has continued to develop ESM. The model has an economic decision-making framework based around the cost of alternative fuels and technologies.

Demand for transport activities were developed from MMRF which is a general equilibrium model used by the Department of the Treasury (the Treasury). The outputs from CSIRO's models were used as an input back into MMRF. The iteration process continued until demand and supply broadly converged.

The scenarios examined in this modelling process were:

- **Central policy scenario** — Assumes a world with a 550 ppm stabilisation target and an Australian emission target of a 5 per cent reduction on 2000 levels by 2020 and an 80 per cent reduction by 2050
- **Low price scenario** — The same as the central scenario except that the stabilisation target is reached at a later date such that the carbon price is initially lower but converges by 2030
- **High price scenario** — Assumes a world with more ambitious global action and an Australian emission target of a 25 per cent reduction on 2000 levels by 2020 and an 80 per cent reduction by 2050
- **No carbon price scenario** – the same global context as the central scenario except that Australia does not participate and there is no domestic carbon price.

The modelling indicates that the transport sector has significant capacity to reduce their emission intensity in the period to 2050 through higher fuel and task efficiency and adoption of lower greenhouse gas emission intensive fuels. However, the measures are generally not sufficient to offset the growth in passenger and freight demand of around 150 to 250 per cent, varying by State and transport mode. Consequently transport sector emission are flat to higher by 2050 under all scenarios (Figure 1-1).

Additional modelling of sensitivity cases finds that:

- Mandatory efficiency standards could increase abatement in the central policy scenario by 3MtCO_2e by 2020;
- Higher or low oil prices would also have a significant impact on projected greenhouse gas emissions;
- Bringing forward the timing of the shift to an emission trading scheme has negligible impact on transport sector greenhouse gas emissions; and
- Excluding the heavy road sector from carbon pricing is projected to result in transport sector emission being 14.5 percent or 12 MtCO_2e higher by 2050.

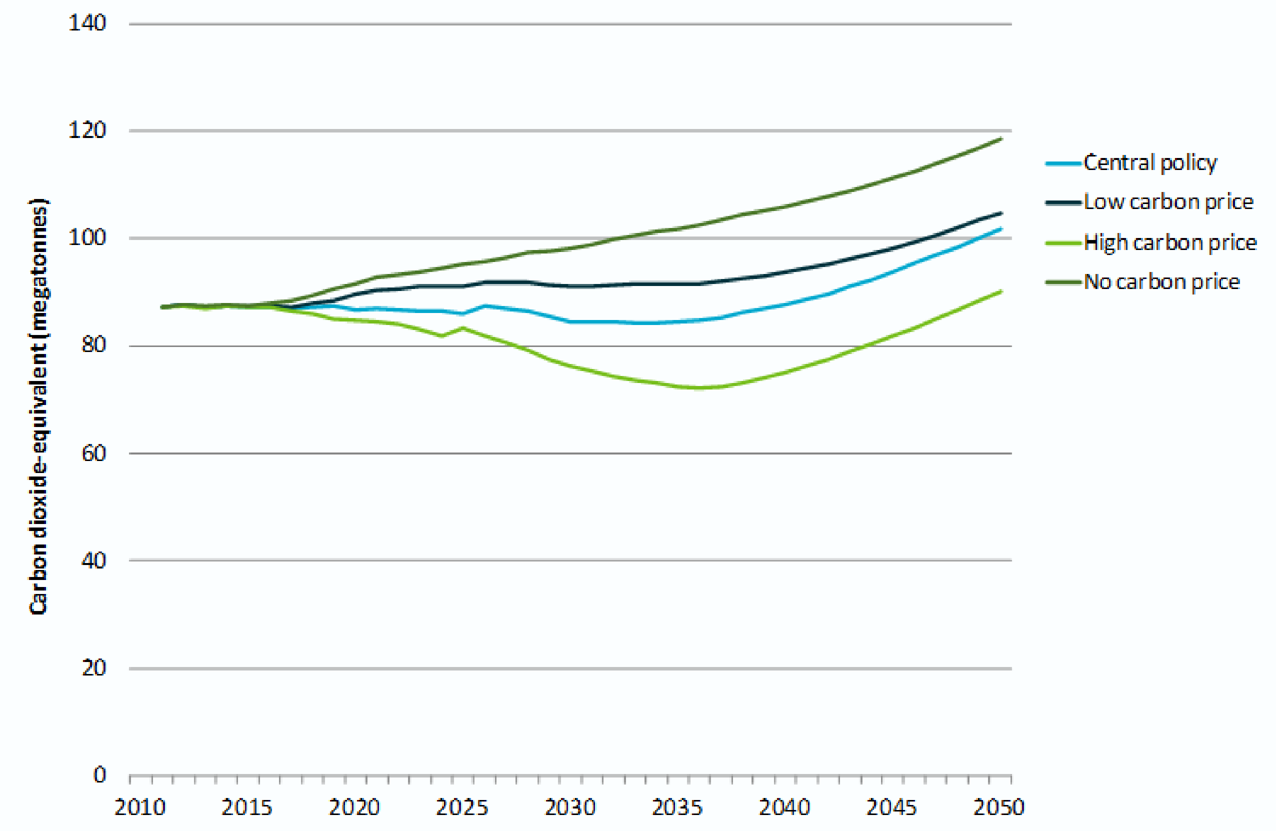

Figure 1-1: Projected transport sector greenhouse gas emissions by scenario

1 Introduction

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The modelling is conducted using a combination of top town approaches in the case of rail and marine transport and a partial equilibrium model covering road and aviation. The partial equilibrium model is called the Energy Sector Model (ESM) and covers the Australian energy sector. The ESM contains nine road vehicle categories including buses, trucks and passenger vehicles. The ESM was developed by CSIRO and ABARE in 2006. Since that time CSIRO has continued to develop ESM. The model has an economic decision-making framework based around the cost of alternative fuels and technologies. Making choices about alternative fuel and technology uptake in the road and aviation sectors is the main task of ESM. Alternative fuel uptake in the marine and rail sector was imposed rather than modelled.

Total fuel demand is projected via applying fuel energy and task efficiency improvement rates to the projected growth in transport activity demand in kilometres or tonnes of freight. Future fuel efficiency estimates were taken from the literature and imposed for each scenario.

The demand for transport was determined by the Department of Treasury using MMRF which is a computable general equilibrium model of the Australian economy and takes into account population growth, the projected output of industries and changes in the cost structure of transport. A central scenario for passenger transport growth was calibrated within MMRF based on data provided by the Bureau of Infrastructure, Transport and Regional Economics (2010). From this starting point various other scenarios are able to project changes in demand based on how the economy is impacted by the scenario assumptions.

With demand for transport activities from MMRF as an input, demand for individual fuels and vehicle types was determined using CSIRO's modelling. The outputs from CSIRO's models were then used as an input back into MMRF. The iteration process continued until demand and supply broadly converged.

This report is set out in six parts including this introduction. The second, third and fourth parts describe the scenarios, the modelling methodology and assumptions in detail. The fifth and sixth parts describe the scenario and sensitivity modelling results.

2 Modelling overview

2.1 Introduction to the modelling exercise

The scenarios modelled in this report are primarily concerned with understanding how the transport sector will respond to a carbon price mechanism that provides a financial incentive for actors within that sector to make choices which result in lower greenhouse gas emissions. In this section we provide a description of the scenarios which set the strength and timing of the price signal and the transport sector modelling assumptions which determine how the sector is likely to the respond to those signals including the relative costs of alternative fuel and engine technologies and sources of inertia such as infrastructure constraints and demand growth.

2.1.1 SCENARIO VERSUS PREDICTION: TREATMENT OF UNCERTAINTY

It is important to understand the distinction between scenario analysis and prediction. Scenario analysis is concerned with projecting what could happen given a specific set of circumstances that are defined in the scenario assumptions. Prediction is concerned with what is likely to happen given all future drivers.

This distinction is particularly important when we consider large transport sector investments such as alternative fuel feedstock development and refining. Within a given scenario where we are confident that a certain carbon price, oil price, technology development will occur, infrastructure investment can be justified if they are profitable under those circumstances. However, in reality, if we were trying to predict investment then we would have to employ a different approach which takes account of all of the uncertainties in the relevant economic drivers and would likely conclude that investment would not proceed at the same pace. This reflects the long standing rule in finance that a high degree of uncertainty in the key economic drivers of largely irreversible infrastructure investment project tends to lead to investment delay in order to allow time to narrow the uncertainty range (Dixit and Pindyck, 1994).

To partially take account of investment uncertainty, the model assumptions generally impose some delay in investments such that they only proceed several years after being theoretically profitable. However, the modelling is still overly optimistic about the amount of certain knowledge that investors would have in reality. Therefore the scenario results should be interpreted as only being indicative of what developments might emerge if the scenario assumptions occur such that most policy, technological and market uncertainty is resolved.

2.2 Scenario overview

The Australian carbon pricing scenarios are developed with reference to two global greenhouse gas abatement scenarios as defined by world greenhouse gas concentration stabilisation targets – 550ppm and 450 ppm. Australian Central, low and no carbon price scenarios are defined using the 550pm global stabilisation target context and an Australian high price scenario uses the 450ppm background. For the purposes of this report the global context has two direct impacts:

- The price of international carbon price permits which, through trade, impact on the domestic price of carbon
- The amount of technological change that is being driven by global greenhouse gas abatement efforts

Indirectly the global carbon price shapes the national economy and therefore transport demand.

Another feature of the scenario architecture is the coverage of the carbon pricing policy. In particular, passenger and light commercial road transport is excluded from carbon pricing indefinitely. The heavy road sector is included but has a brief exclusion period to 2013-14. Table 2-1 describes the global scenario context and carbon policy coverage

Table 2-1: Global scenario context

	Central and low price scenarios	High price scenario
World stabilisation target	550 ppm	450 ppm
Australian emission reduction target	5 per cent below 2000 levels by 2020; 80 per cent below 2000 levels by 2050	25 per cent below 2000 levels by 2020; 80 per cent below 2000 levels by 2050
Allocation	Taken as Australia's Quantified Emission Limitation or Reduction Objective trajectory as described in Australia's submission under the Kyoto protocol; and from 2020 as a straight line to achieve the 2050 target.	Set as a straight line reduction: from the end of the Kyoto commitment period (2008-2012) to achieve the 2020 target; and from 2020 to achieve the 2050 target.
International linking	No international linking during the fixed price period. Linkage to the EU ETS (initially as a one-way link) from 2015 to 2020 with quantitative restrictions to ensure liable parties meet at least 50 per cent of their annual liability from domestic permits and credits until 2020, and no more than 6.25 per cent through CERs in 2015 and 12.5 per cent in other years. Transition to a common international price from 2021	
Coverage	All emission sources are covered, except: * activity emissions from agriculture and forestry; * combustion emissions from agriculture, forestry and fishing; * on-road combustion of liquid fuels by light vehicles and gaseous fuels; * on-road combustion of liquid fuels by heavy vehicles in 2012-13 and 2013-14; * decommissioned mines; * land-use change; * legacy waste; and * existing synthetic gases.	
Emission-intensive trade-exposed activities (EITE)	Assistance to activities starts at 94.5 per cent or 66 per cent, depending on intensity. LNG facilities receive assistance of a minimum 50 per cent of emissions. The steel industry receives a 10 per cent increase in permit allocations from 2016-17. Assistance declines at an annual rate of 1.3 per cent per year before being assumed to phase out in five steps beginning in 2022. Estimates of activity level assistance for 2012-13 are allocated to MMRF industries based on currently approved activities and scaled with industry gross output in subsequent years.	
Fuel	An effective carbon price is applied to: businesses' combustion of liquid fuels from 2012-13 (except light vehicles, agriculture, forestry and fishing) and heavy on-road vehicles from 2014-15, through the fuel tax credit system; and aviation fuel from 2012-13 through the domestic aviation excise system. Private passenger cars are excluded.	

2.2.1 SCENARIOS DEFINED

With this background the four scenarios modelled in this report are as follows:

- **Central policy scenario** — Assumes a world with a 550 ppm stabilisation target and an Australian emission target of a 5 per cent reduction on 2000 levels by 2020 and an 80 per cent reduction by 2050

- **Low price scenario** — The same as the central scenario except that the stabilisation target is reached at a later date such that the carbon price is initially lower but converges by 2030

- **High price scenario** — Assumes a world with more ambitious global action and an Australian emission target of a 25 per cent reduction on 2000 levels by 2020 and an 80 per cent reduction by 2050

- **No carbon price scenario** – the same global context as the central scenario except that Australia does not participate and there is no domestic carbon price.

The carbon prices associated with these policies are shown in Figure 2-1.

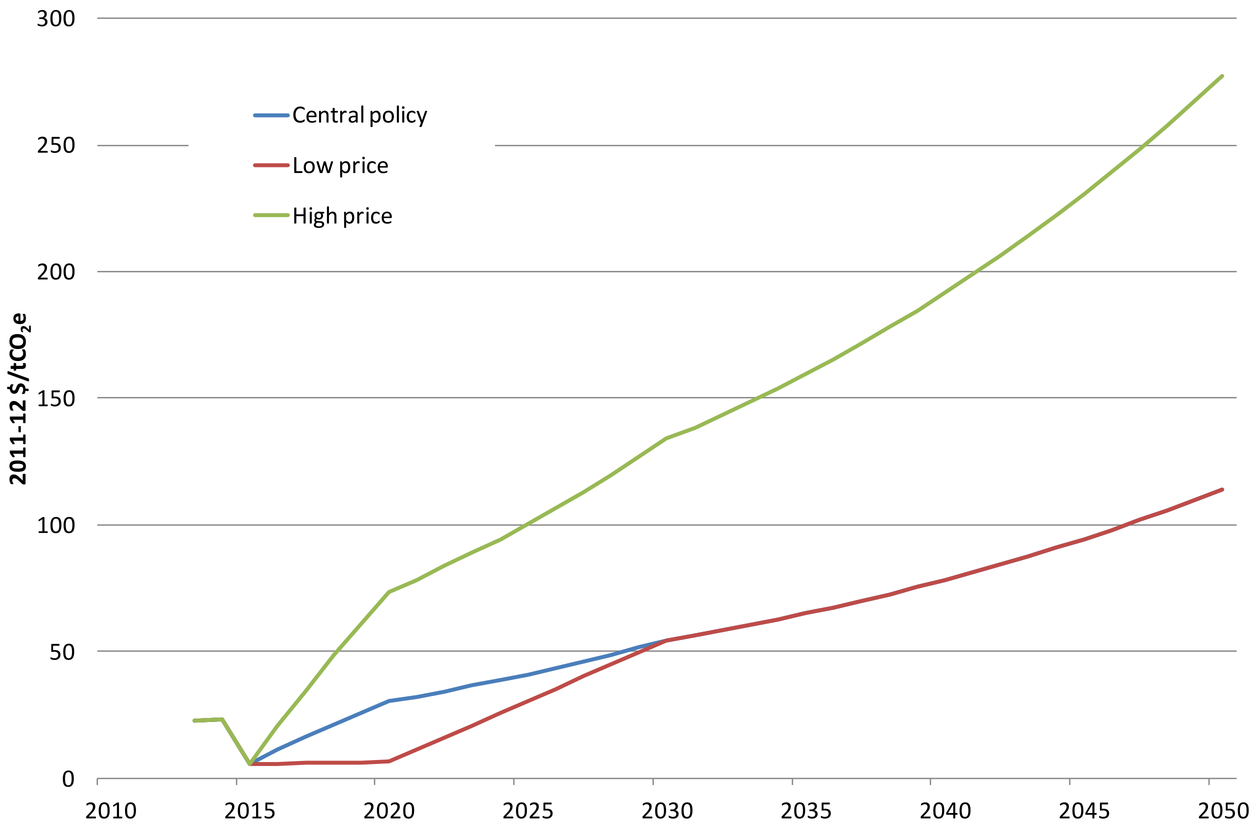


Figure 2-1: Carbon price assumption by scenario

Another very important scenario assumption is the oil price which also determines the gas price due to their partial substitutability in global energy trade. The price of oil can be an even stronger driver than carbon prices. To illustrate, a carbon price of $10/tCO_2$e can increase the petrol price by around 2.5 cents per litre. However, oil price changes alone have been responsible for petrol price increase of around 60 cents per litre in the 10 years to 2013 – the equivalent of a $240/tCO_2$e price signal. The consumer response to rise in oil prices has been more evident in adoption of higher fuel efficiency vehicles rather than any major changes to kilometres travelled.

The scenarios all assume further increases in the price of oil and gas and these assumptions are reported in the Department's main report. Given the oil price change is very similar across the scenarios this assumption will not be a source of differences between the scenario projections. The most important impact of the assumed rising oil price, to around 2011-12 A$190/bbl by 2035 is on the economic viability of alternative fuels. At this future oil price, nearly all types of alternative fuels will have some resources which are cost competitive with oil. In the assumptions section we outline how these oil and gas price assumptions impact prices of final fuels such as petrol, diesel and liquefied natural gas.

2.3 Sensitivity cases overview

Five sensitivity cases were modelled to examine the impact of some specific drivers or alternative assumptions. The sensitivity cases are as follows:

- **Minimum emission standards for new cars** - a sensitivity case which assumes that mandatory CO_2 emissions standards on all (imported and domestically produced) new light vehicles (passenger and light commercial vehicles) apply from 2015. The average emissions for new light vehicles sold in Australia in the years 2015-2020 must meet an average CO_2 emissions target of 190g/km from 2015 onwards and 130g/km from 2020 onwards.

- **No carbon price on heavy road vehicles from 2014** - a sensitivity case which assumes that the heavy road vehicle segment of the transport sector (rigid trucks, articulated vehicles and buses) are exempt from a carbon price for the entire projection period. This sensitivity case essentially means that only the non-road transport sector is subject to carbon pricing

- **High oil prices** – a sensitivity case to gauge the impact of high oil prices on the central policy scenario. Under the central policy scenario, oil prices are $134/bbl in 2020, $190/bbl in 2035, and are assumed to remain constant at that level to 2050. Under the high oil price sensitivity case, oil prices are $144/bbl in 2020, $220/bbl in 2035, and are assumed to remain constant at that level to 2050. All prices are in 2011/12 Australian dollar terms

- **Low oil prices** - a sensitivity to gauge the impact of low oil prices on the central policy scenario. Under the central policy scenario, oil prices are $134/bbl in 2020, $190/bbl in 2035, and are assumed to remain constant at that level to 2050. Under the low oil price sensitivity case, oil prices are $125/bbl in 2020, $160/bbl in 2035, and are assumed to remain constant at that level to 2050. All prices are in 2011/12 Australian dollar terms.

- **Emission trading commenced in 2015/16** - a sensitivity on the central policy scenario assuming that Australia adopts an emissions trading scheme in 2015/16 rather than in 2014/15 as under the central policy scenario.

3 Modelling methodology

The road sector is particularly amenable to partial equilibrium modelling of vehicle, fuel and engine choices. There is sufficient data for the whole cost of road transport to be estimated and modelled as a consumer choice optimisation problem. Data on vehicles, fuel and insurance are transparently provided by various suppliers. Government provides the excise framework and also the essential road infrastructure in response to demand but this additional cost is socialised through the tax system and so does need to be bundled with an individual's selection of vehicle and fuel type.

On the other hand the marine, aviation and road sectors include more application dependent vehicles, less transparent cost components and a greater degree of privatisation in the planning and supply of infrastructure such as ports, rail lines and airports. Decisions about the underlying infrastructure may need to be bundled together with the vehicle purchase decision. Consequently, modelling a generalised whole cost of transport in these non-road sectors cannot be approached with the same degree of confidence unless conducted at a finer spatial scale or on a more project specific basis than is practical for national emissions modelling. Consequently the road sector modelling applied in this report is strongly economics-based in the case of the road sector and more assumptions based in the case of the marine, aviation and rail sectors. We expand on these approaches in the following sections.

3.1 Non-road transport modes: projection methodology

This section describes the approach taken by CSIRO to model the non-road transport modes in the context of integrated bottom-up and top-down transport sector emissions projection modelling.

3.1.1 PROJECTING ACTIVITY DEMAND

Non-road transport is characterised by strong infrastructure constraints (port access, airports, rail lines) and long lived vehicle fleets (minimum 20 years life of assets the norm compared to over 90 per cent of road vehicles retired by this age). Ideally any modelling of non-road transport sectors would take into account these specific features. However, given the diversity of Australia's states and the unpredictability of infrastructure investment CSIRO applies an alternative top-down based approach.

The top-down approach assumes that demand is driven by population and industry activity that is a function of the general level of economic activity and that infrastructure needs will keep pace to meet that demand. A major advantage of this approach is that it is very amenable to modifying demand projections in response to scenarios that impact the economy in general such as major tax reform or industry restructuring.

The approach is implemented across two models. Firstly, a general equilibrium model of the economy (in this case MMRF) is calibrated to recognise the current adoption rates and tendency towards saturation in non-road passenger demand growth. Industry output is recognised as the main driver of non-road freight demand growth such that as industries that require freight as an input expand, freight demand expands accordingly. MMRF also implements an elasticity which allows for a modest amount of mode substitution between road and rail freight.

The non-road transport passenger and freight demand growth projection from MMRF is fed into a second model which converts the projection, which is expressed as a growth index, into physical units of transport such as passenger and tonne kilometres. The growth rates for the passenger task are applied directly to extend baseline passenger kilometres into the future. However, for the freight task we assume that task efficiency improvements will mean that tonne kilometres increase more slowly than the MMRF index (which is interpreted as tonnes of freight). The rate of improvement in task efficiency is extrapolated from past observations.

3.1.2 PROJECTING FUEL DEMAND

Fuel demand is projected by applying a fuel energy efficiency (MJ/km) improvement rate to the projected growth in non-road transport activity demand (km). The projected change in fuel efficiency represents a collection of multiple drivers for each mode. For example, in rail it could include regenerative breaking or alternative conversion technologies such as fuel cells. In marine transport it could include higher quality fuel, streamlining port logistics and tailoring shipping routes to expected weather and currents. In air transport it could include air traffic management and operation, aircraft light weighting and airframe aerodynamics.

Future fuel efficiency estimates are taken from the literature and imposed for each scenario. As a general rule, given most fuel efficiency improvements are self-financing via fuel cost savings, around half of the available efficiency improvement potential described in the literature is assumed to occur under business as usual conditions. Under further economic drivers such as higher oil or carbon prices, a portion of the remainder of the efficiency improvement potential is assumed to be accessible.

3.1.3 FUEL SELECTION

Given the long lived nature of non-road transport vehicles, fuel choice is one of the most important options available to the non-road sector for reducing greenhouse gas emissions given its relative flexibility. For most of the projection period we would expect non-road vehicles and the engines they employ to be largely the same as today. Table 3-1 below describes the fuel use options that we allow for each non-road sector.

Table 3-1: Allowable mode and fuel combinations

	Aviation	Rail	Marine
Jet fuel	✓		
Bioderived jet fuel	✓		
Gasoline	✓		✓
Electricity		✓	
Diesel		✓	✓
Biodiesel		✓	✓
Natural gas		✓	✓
Fuel oil & coal			✓

The aviation sector has the most limited fuel choices because jet aircraft require specific fuel qualities that are only found in kerosene (e.g. low freezing point, low flash point, high energy density). Bio-derived jet fuel meets these requirements and can be sourced from a variety of feedstocks and refining pathways. Gasoline (called avgas) can be used in light aircraft and has less stringent requirements but as this is a very small part of total aviation fuel use, substitutes for this fuel are not explored.

As the electricity sector decarbonises the emission intensity of electrified rail will naturally decline[1]. However, as carbon and oil prices increase, diesel fuelled rail is likely to look towards natural gas and biodiesel as possible substitutes for oil derived diesel. Depending on the refining process, biodiesel can be produced which requires no change to the rail fuel storage and engine systems. However, incorporation of natural gas in its compressed or liquefied form would require modified storage and engine systems. Also note that a portion South Australia's diesel passenger rail transport will be electrified from 2014.

Part of the evolution of marine transport, other than in response to oil or carbon price pressures, is simply to switch from lower grade fuel oil to diesel. This is occurring as part of international agreements to clean up marine shipping emissions for air pollution and greenhouse gas emissions purposes. Going beyond diesel, marine will have much the same options as rail to incorporate biodiesel and natural gas as substitutes for oil based diesel.

Note that sources of conventional fossil diesel could also be derived from coal, gas or shale rather than oil as the primary energy sources. However, in the non-road transport model we do not seek to make these distinctions[2].

With this fuel choice menu we proceed to take a different approach for aviation as compared to rail and marine transport to impose a fuel selection over time. For aviation transport we use CSIRO's Energy Sector Model (ESM) to project the uptake of bio-derived jet fuels in aviation. We use this approach because form past experience we find that the aviation sector, given its relative lack of fuel choice, is eventually a strong competitor for biomass resources. ESM is

[1] Electricity sector emissions have been declining since 2009
[2] These are explored in road sector modelling

able to determine the timing and volume of bio-derived jet fuel taken up in aviation by forcing the sector to directly compete with the road and electricity sector for this resource[3]. The timing of when the aviation sector is able to compete with the road sector for biomass energy resources is heavily influenced by the timing of uptake of electric vehicles in the road sector.

In the marine and rail sectors the uptake of biodiesel is not modelled but imposed. The uptake rate is assumed to be smaller and slower than for aviation given that the marine and rail sectors have a wider range of options to choose from and generally do not pay a premium for their fuels relative to road and aviation sectors. Natural gas adoption is assumed to occur at a similar rate to biodiesel being motivated by the same pressures of cost minimisation and greenhouse gas reduction. Assumed adoption rates are increased for alternative scenarios depending on the extent to which incentives to fuel switch have changed.

There is a small amount of coal used as marine fuel in Queensland. This is assumed to be phased out in the 2030s based on end of life retirement of the relevant fleet. Substitutes for recreational boating use of gasoline are not explored due to the low volumes.

3.1.4 EMISSIONS PROJECTION

The flow of logic from economic growth, transport activity via task efficiency to fuel consumption via fuel efficiency and fuel selection is almost all that is required to project emissions. The final step is to apply a fuel emission factor which is sourced from the National Greenhouse Gas Inventory accounting methods. Biofuels and electricity emission factors are assumed to be zero to avoid double counting and to recognise that direct emissions associated with the combustion of biofuels are offset by carbon absorbed during the production of biomass feedstocks. Electricity sector emissions are accounted for separately in electricity sector modelling as are upstream refining sector emissions. All other fuels have positive emission factors which remain constant over time.

A summary of the end to end modelling process is shown in Figure 3-1 below.

[3] Electricity demand for biomass is inputted as a constant assumption based on modelling conducted outside of ESM. However, ESM can determine this amount independently as required.

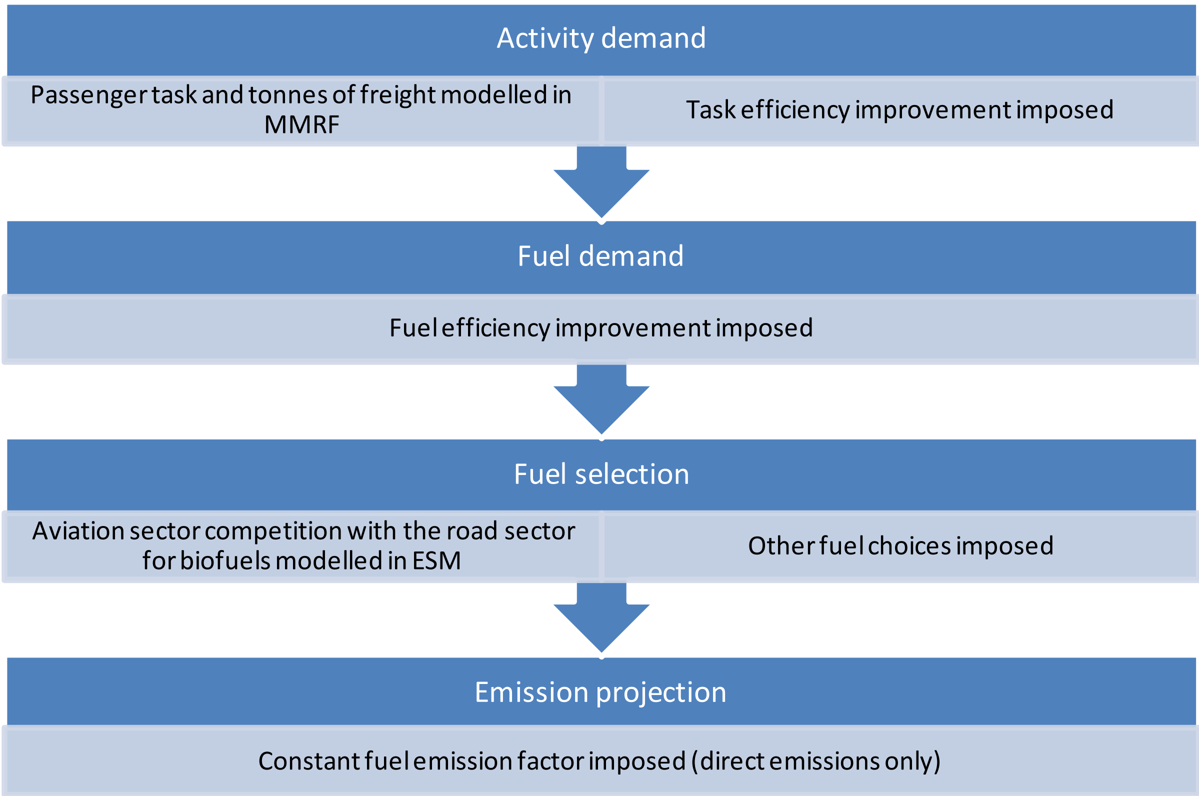


Figure 3-1: Overview of non-road greenhouse gas emission projection process

3.2 Road sector modelling

ESM is a linear programming model of the electricity and transport sectors. The version of the model applied to this modelling exercise concerns the transport sector only and determines the least cost mix of fuels, vehicles and other inputs to meet a given transport services demand subject to policy or other constraints such as the rate of stock turnover.

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.

A detailed description of ESM is provided in Appendix A.

3.2.1 LIMITATIONS OF ESM

The most powerful aspect of ESM is that it is able to provide economically consistent projections of road sector fuel and vehicle choices. Projections can be logically understood as economic choices within a set of physical constraints. As with all models, the approach has some 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 with the greatest uncertainty include possible breakthroughs in so called “second or advanced generation” biofuel production technologies and the unknown quality and cost of future offerings of fully and partially electrified vehicles.

A second 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 “fast 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 “fast 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 starting point for shifts in preferences for new technologies could be considered conservative.

Another factor which ESM can overlook is community acceptance. 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 natural gas 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 primarily considers whether the choice is economically viable. Graham and Smart (2011) provides some sensitivity analysis of alternative ESM assumptions with respect to electric vehicle payback periods. However, in this study we assume 5 years across all scenarios.

As a result of these limitations, the technology and fuel uptake projections 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. The modelling is specific to Australia taking into account our particular vehicle preferences, fuel excise system and energy resources.

3.2.2 FUELS THAT WERE EXCLUDED AND OTHER KNOWLEDGE GAPS

It is the goal of all model designs to include enough information to represent the main current and future drivers for a given sector of interest and no more. Judgement of this cut-off point is subjective. In the timeframe available for this modelling exercise it was not possible to make significant changes to the scope of ESM. Therefore, only the existing list of 14 fuels that CSIRO had included in the model could be examined as part of this modelling exercise.

Several fuels such as biogas, dimethyl ether (DME), methanol, butanol and compressed air could not be modelled as they are not currently included in ESM. It is important that the reader recognise that exclusion of these and any other candidate fuels is not an indication their lack of potential. The authors acknowledge that until these fuels are included in a similar modelling exercise, how they would have fared - relative to the fuels that were included - is unknown.

4 Key Assumptions

4.1.1 TRANSPORT SECTOR DEMAND DATA

Population growth, economic growth and the existing level of use (saturation) of a transport mode are the three key drivers of transport demand growth. The demand for transport was determined by the Treasury using MMRF, which is a general equilibrium model of the Australian economy and takes into account population growth, the projected economic growth of industries and changes in the cost structure of transport. As MMRF does not have a measure of saturation within the model a central scenario for passenger transport growth was first calibrated within MMRF based on data provided by the Bureau of Infrastructure, Transport and Regional Economics (2010) (Figure 4-1). From this starting point MMRF can project changes in demand for the other scenarios based on how the economy is impacted by the assumptions.

In effect this approach to demand modelling means freight transport modes experience growth in demand reflecting growth in the economy and more specifically the transport freight intensive sectors - for example, the mining sectors use of rail for bulk goods transport in states such as Queensland and Western Australia (Figure 4-2).

However, passenger sectors experience growth in demand that is closer to growth in population the more saturated their demand. Passenger road demand is the mostly heavily saturated (meaning it is close to the point where users cannot easily consume any more, reflecting time and other lifestyle constraints). Aviation is the least saturated and so there is significant potential for higher adoption and therefore growth at faster than the population growth rate.

Note MMRF does not distinguish aviation passenger and freight demand, although passenger would be the dominant share. Similarly marine transport is also not disaggregated into passenger and freight but would be mostly freight.

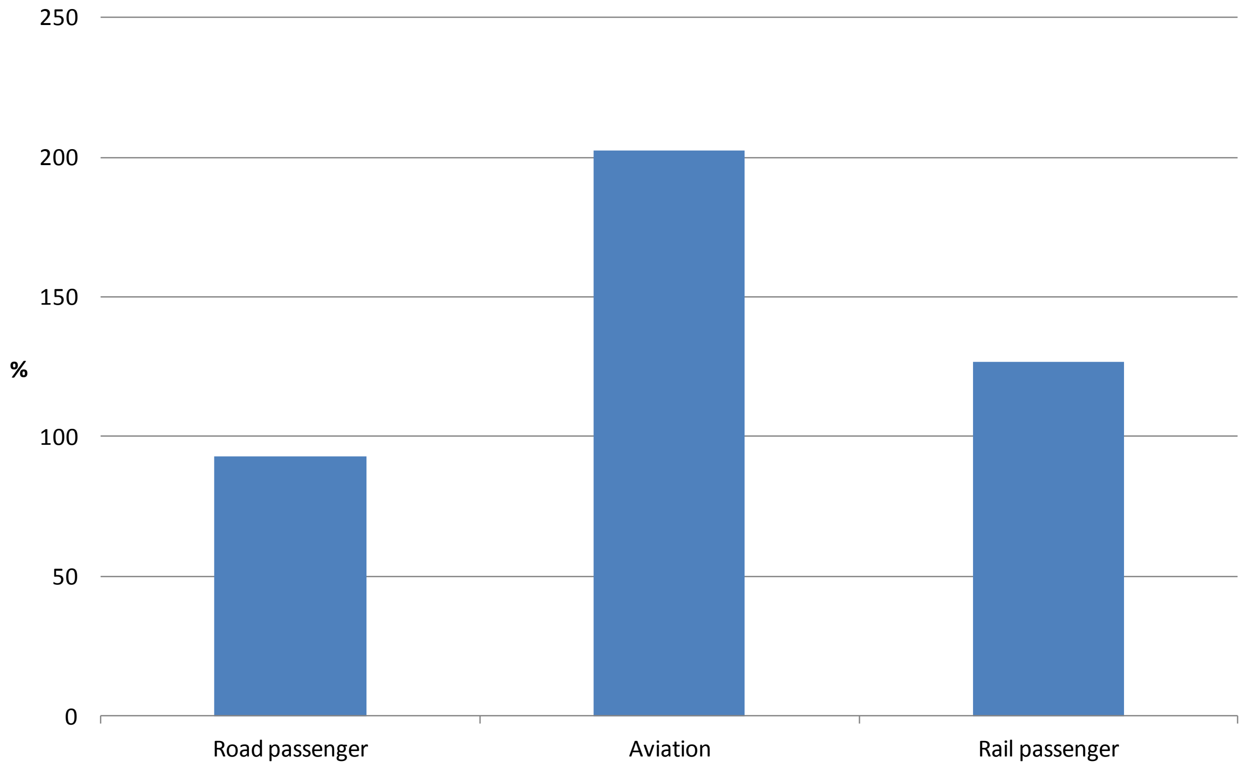


Figure 4-1: Calibrated passenger transport growth to 2050 in the central policy scenario

MMRF projects freight transport by state based on the demand for freight by other sectors within the economy. Rail freight is projected to increase up to 450 percent in some states. In most states, rail, marine and road freight growth is between 150-250 percent by 2050.

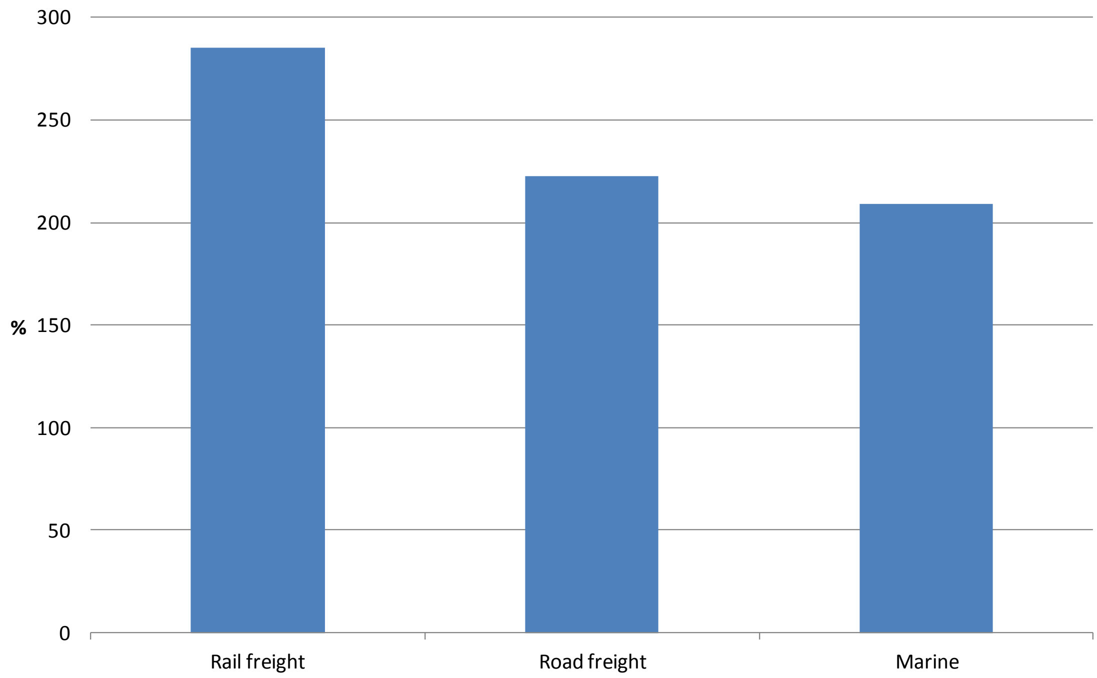


Figure 4-2: Projected freight growth to 2050 in the central scenario

The off-road vehicle sector, international shipping and aviation are excluded from this modelling activity and are not accommodated for in the transport sector demand data.

Fuel consumption will not increase to the same extent as transport demand due to expected improvements in fuel and activity efficiency. Fuel efficiency depends on the fuels and technologies taken up in each scenario. In regard to activity efficiency, for rail freight and marine transport, historical data on goods moved measured in tonne kilometres and in total tonnes have been examined to formulate a “task improvement” adjustment factor (e.g. larger ships/longer trains hauling more freight for same kilometres travelled). Using the longest sample for each mode, rail shows an average 1.9% improvement p.a. and shipping 0.43% p.a. These rates are assumed to continue indefinitely.

4.1.2 DRIVERS OF ROAD FUEL AND VEHICLE CHOICES

Economic and other considerations

In the road passenger sector, a multitude of factors influence the type of vehicles that are purchased each year. ABS (2009) reviewed a number of factors including purchase cost, fuel economy and size of vehicle. They found that the purchase cost was the strongest amongst this group (Table 4-1).

Table 4-1: Ranking of surveyed factors considered in buying a vehicle from ABS (2009)

Ranking	Vehicle purchase considerations
1	Purchase cost/price
2	Fuel economy/running costs
3	Size of vehicle
4	Type of vehicle (e.g. car, 4WD)
5	Reliability
6	Appearance
7	Manufacturers reputation
9	Age/low kilometres
10	Safety
11	Seating capacity
12	Accessories (e.g. air conditioning)
13	Engine capacity/performance
14	Other
15	Environmental impact/exhaust emissions

The approach applied in this analysis assumed that alternative fuels and vehicles will be taken up when they represent a cost saving relative to other choices for both freight and passenger sector users. This is a necessary oversimplification in order to make the analysis of the future potential of alternative fuels tractable. However, how consumers decide what is an economically rational choice is not straightforward. Consumers react to fuel prices daily but have limited ability to change their fuel choice once their vehicle has been purchased. For example, E10 is compatible with most modern vehicles and E85 in a more limited range of vehicles. Alternative forms of diesel from fossil or renewable sources are also partly or fully substitutable. In these circumstances, the choice is simply choosing the least cost fuel (adjusting for any changes in energy content if applicable).

At the point of vehicle sale or when considering a retrofit, when a broader range of options are available, the rational choice would be to compare the full running cost of each vehicle over the period of ownership, including vehicle purchase cost, registration, maintenance and fuel. The NRMA's 2011 *Private Whole of Life Fixed Vehicle Operating Costs* estimate that such costs range between 40 to 80c/km for small to large passenger vehicles.

The approach adopted ignores the role of fast adopters, who have a preference for more advanced vehicles which often do not represent a rational economic choice. However non-economically rational choices may satisfy demands for more environmentally sustainable or technological advanced vehicles. The limitations in the model framework design to account for non-economically rational choices, such as consumer acceptance and 'fast adopters,' has already been noted in the methodology discussion.

Whilst economic considerations drive most vehicle purchase decisions in the modelling, the analysis does impose assumptions with respect to preference for vehicle sizes. It is assumed that there will be a trend to smaller vehicles occupying a greater share of the road fleet reflecting recent trends in response to higher oil prices since 2004 (see Figure 4-3 below).

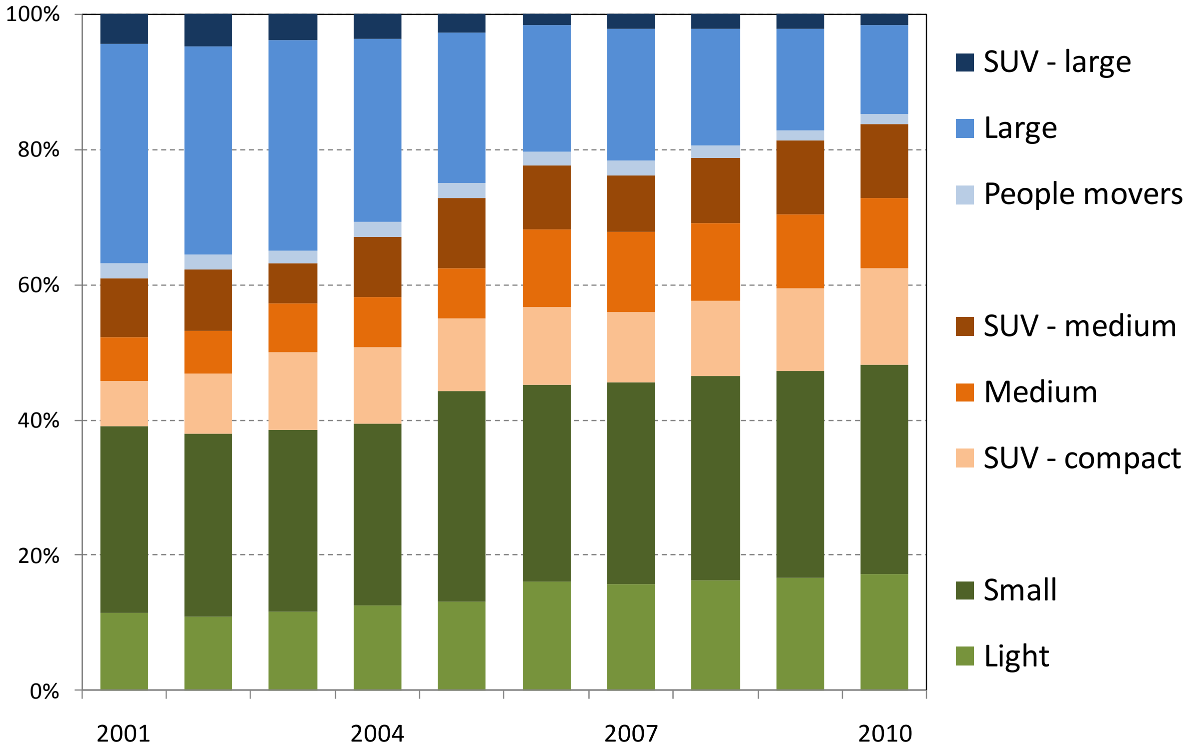


Figure 4-3: Changes in preferences for road vehicle types and sizes, FCAI (2011)

In the road freight sector, as users are commercial operators, economic considerations such as profit motivation are a much greater concern and subsequently any potential savings are assumed to be actively pursued. The same assumptions are made for operators in rail, domestic aviation and shipping.

Switching costs

Road vehicle costs include a mix of upfront and running costs. It is generally acknowledged that private and commercial consumers have a preference for avoiding upfront costs. This is an issue for alternative fuels because many options such as vehicle electrification, fuel cells and use of natural gas or LPG involve higher upfront costs. On the other hand, it may be possible to address the issue of upfront costs via financing and mixed ownership models. With the exception of diesel, these upfront costs are assumed to decline in the long term by approximately 50 percent in the period to 2050.

Table 4-2: Table of current additional up-front road vehicle costs of alternative fuels in A$,000

	Passenger [a]	LCV [a]	Rigid truck	Articulate truck	Bus
Diesel	3	3	NA	NA	NA
LPG	2.5	2.5	30	65	55
CNG	5.5	5.5	37	NA	60
LNG	NA	NA	NA	50	NA
B100	0	0	0	0	0
B20	0	0	0	0	0
E85	0	0	NA	NA	NA
E10	0	0	NA	NA	NA
Fuel cell	35	35	80	150	140
GTL	0	0	0	0	0
CTL	0	0	0	0	0
STL	0	0	0	0	0

a Larger sized vehicle

Social constraints to the uptake of electric road vehicles

Most alternative vehicles require little adaptation by the user. For example some gas fuelled vehicles require a change in location of the fuel tank. However, electric vehicles (EVs) could require more significant adaptation because of their reduced range of around 100 km and battery recharge could take several hours depending on the technology. Sensitivity cases examining that issue were explored in Graham and Smart (2011). We use the “Scenario 2” assumptions for electric vehicle uptake from that previous work which assumes a reasonable level of social acceptance, particularly amongst two vehicle households.

4.1.3 EXPECTED FUEL EFFICIENCY IN THE ROAD SECTOR

The United Kingdom’s *King Review* (2007) and various other recent studies tend to agree that a 15 to 25 percent improvement in the fuel efficiency of internal combustion engines can be expected in the next 10 to 20 years. This modelling exercise assumes this improvement in fuel efficiency is achieved by 2030. It is further assumed that a significant amount of the improvement occurs in the first half of the period to 2030 owing to the deployment of innovations that were sparked by the high oil prices in the mid-2000s.

Petrol vehicles are assumed to improve at the higher end of this range (25 percent) due to their lesser state of development relative to diesel engines. Diesel engines improve at the lower rate of 15 percent. LPG and natural gas vehicles are assumed to rapidly catch up to and keep pace with diesel energy fuel efficiency. The more rapid change in their fuel efficiency reflects the fact that since they have a relatively small vehicle stock it will take less time for improvements in new vehicles to raise the average fleet efficiency.

The efficiency improvements will occur independently of changes to vehicle drivetrains such that overall fuel efficiency improvements after vehicle electrification and/or hybridisation is adopted will be even greater. The adoption of alternative drivetrains is endogenously determined within the model based on cost minimisation.

Table 4-3: CSIRO average light vehicle fuel efficiency improvements inclusive of uptake of alternative vehicle drivetrains (percent per annum)

	2010-2020	2020-2030	2030-2040	2040-2050
No carbon price	1.7	1.5	1.4	0.6
Central policy	1.7	1.8	1.9	0.6
High carbon price	1.7	2.4	2.9	0.6
Low carbon price	1.7	1.9	1.8	0.6

4.1.4 FUEL MIX AND FUEL EFFICIENCY CHANGES IN THE NON-ROAD SECTOR

Aviation

Jet fuel is a type of kerosene. Jet fuels must meet stringent international technical and safety standards. Synthetic jet fuel with the same properties as petroleum-based jet fuel can be made from coal, natural gas or biomass. These synthetic fuels are referred to as 'drop-in' fuels because they can be used without changes to engine fuel systems and distribution and storage systems.

While more advanced processes are under development to reduce costs, refining processes already exist which can convert biomass into jet fuel. Standards for two types of bio-derived jet fuels have approved by the global governing body, ASTM International. They are Synthetic Paraffinic Kerosene (FT-SPK) based on the Fischer Tropsch gasification process for solid fuels such as lignocellulosic biomass; and Bio-SPK based on deoxyhydrogenation of vegetable oils and animal fats.

An updated view of aviation sector fuel options was released in May 2011 in an industry road map report called *Flight Path to Sustainable Aviation*[4]. The report outlines the reasoning why bio-derived jet fuel would appear to be the main sustainable alternative fuel option for the industry and its overall potential. Consequently, bio-derived jet fuel is the only alternative fuel considered for aviation within the model.

The road map was supported by a modelling study by Graham et al. (2011) which outlines the refining process for bio-derived jet fuel, the potential feedstocks, emission factors and potential for future improvements. These assumptions remain hardwired into ESM and given their detailed coverage in the public reports referred to they are not repeated here.

There is also a small quantity of aviation fuel consumed in Australia called avgas that is not jet fuel. Consumption of this avgas is assumed to be stable with no substitution of alternatives.

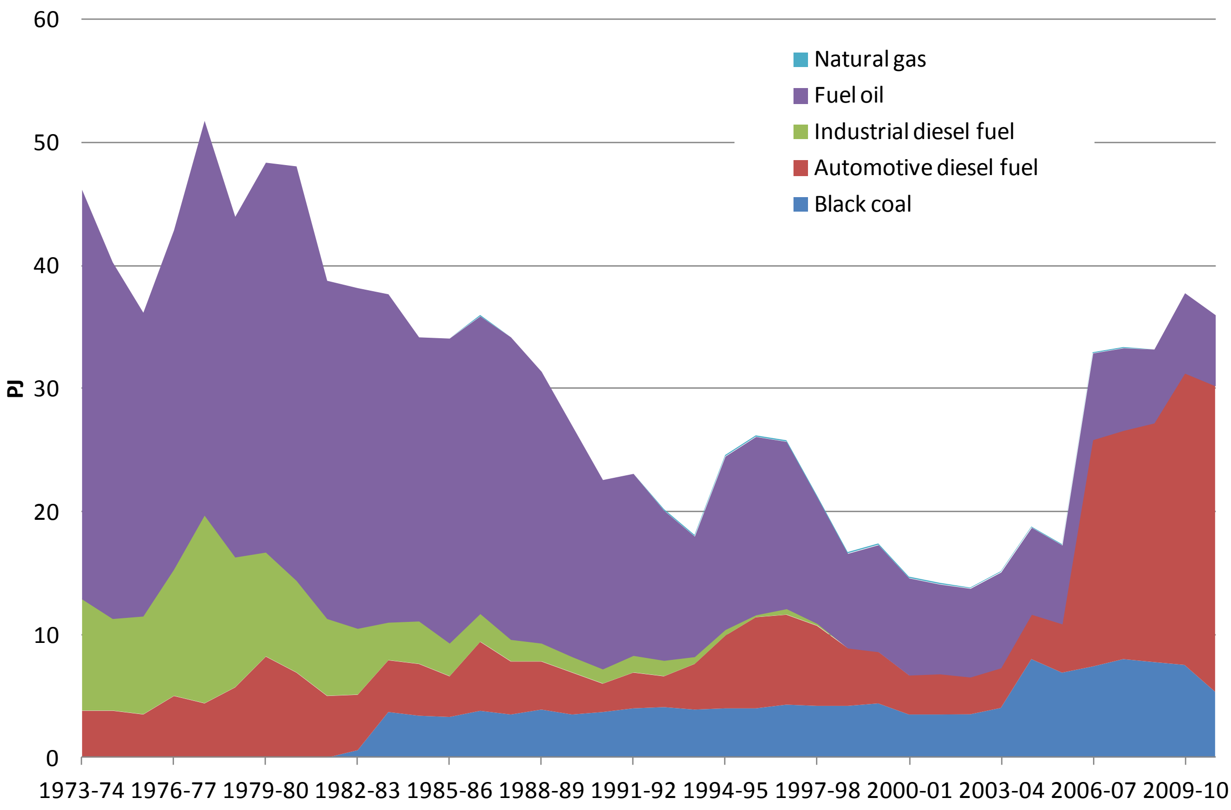
[4] Available at this web site: http://www.csiro.au/science/Sustainable-Aviation-Fuels-Road-Map.html

Given the aviation sector is assumed to be pursuing bio-derived jet fuels which meet the fuel standards for existing aircraft when supplied in up to a 50 percent blending ratio with conventional jet fuel there are effectively no significant fuel switching costs in regard to aircraft modifications. ESM determines when it is economic to switch based on the relative fuel costs of fossil and bio-derived jet fuel inclusive of any carbon prices.

Rail and marine transport

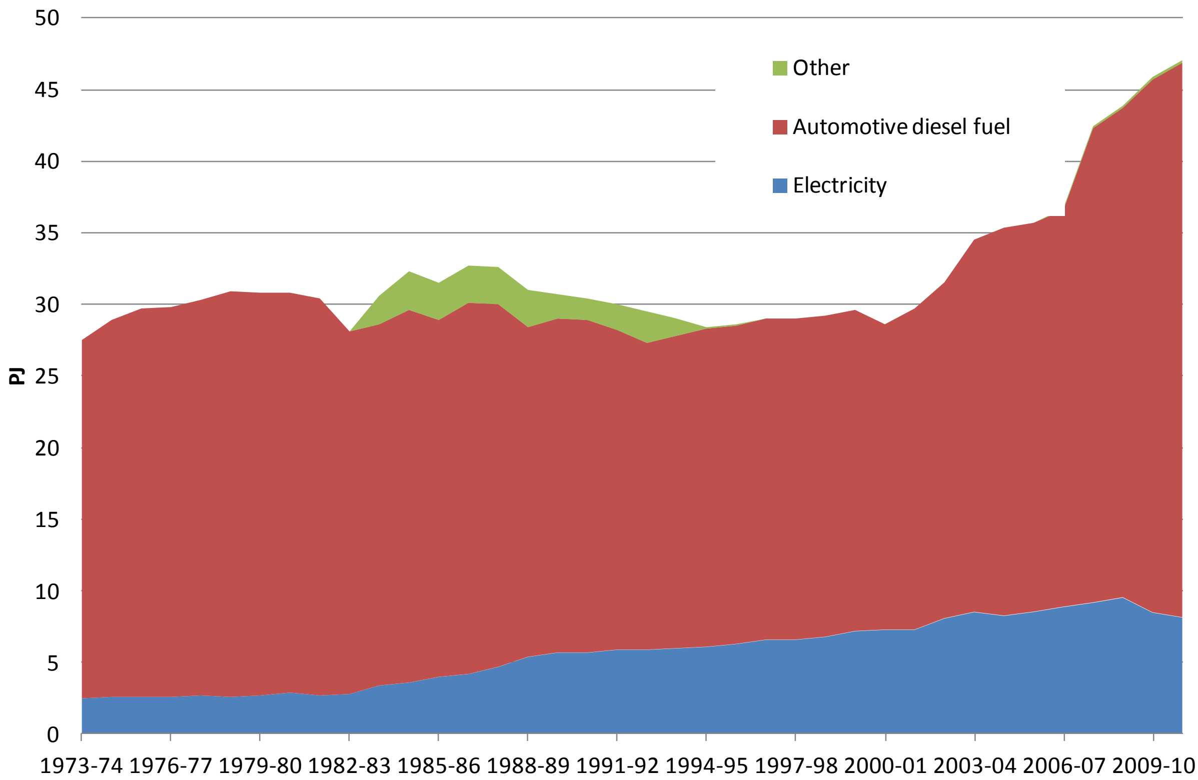
For the rail and marine sectors fuel choices are imposed rather than modelled outcomes. As such, the fuel switching costs for the rail and marine sectors are not directly considered in the modelling. However, we justify imposing a slow partial transition to diesel substitutes such as natural gas and biofuel on the basis that these sectors have high transport asset costs, long commercial lives of infrastructure, and a high degree of end-use customisation. These factors lead fuel users to look for fuels that work with existing diesel engine platforms.

Past trends in the fuel mix are extrapolated. In marine transport the change to greater use of automotive diesel is notable. It is assumed that coal is phased out in the 2030s. In rail transport the use of diesel and electricity is largely assumed to be fixed in their current share of servicing the passenger (predominantly electric) and freight (predominantly diesel) sectors.



Source: BREE (2013)

Figure 4-4: Historical domestic marine transport fuel mix



Source: BREE (2013)

Figure 4-5: Historical rail transport fuel mix

Non-road alternative fuel shares and overall efficiency improvements

A modest market share of biofuel and natural gas is assumed to be achieved by 2050 in both rail and water transport reducing the use of existing fuels. The assumptions differ by scenario and are presented in Table 4-4.

The relatively conservative assumptions for rail and marine alternative fuel uptake reflect the fact that other parts of the transport sector will like have stronger drivers for natural gas and biofuel uptake. Therefore marine and rail use of these fuels will be somewhat more niche. The road and aviation sectors will be prepared to pay a larger premium for biofuels because of initial excise differences in the case of road and because of more limited fuel substitution choices in the case of aviation. The trucking sector will be a strong competitor for natural gas.

The no carbon price scenario has relatively high uptake since the oil price is the main driver. However, incrementally more uptake is assumed to occur for higher carbon prices reflecting the lower greenhouse gas intensities of these fuels.

Fuel efficiency improvements are based primarily on Cosgrove et al (2011) which provided estimates of the maximum achievable efficiency improvements on technical grounds by 2050 (largely ignoring costs but not imposing too much social change). For example aviation could achieve 40-50 percent improvements in efficiency, marine 30 percent. The approach taken is to assume a portion of this would be achievable given the oil and carbon price signals would overcome some cost barriers. Similar to the approach taken with alternative fuel shares, most of the efficiency improvement is achieved without a carbon price, but higher carbon prices lead to incrementally more efficiency improvement.

Table 4-4: Assumed shares of natural gas and biofuels in the fuel mix and fuel efficiency improvement by 2050

		Natural gas	Biofuels	Fuel efficiency improvement
		%	%	%
Marine	Central policy	12.5	12.5	20
	Low price	12	12	17.5
	High price	15	15	22.5
	No carbon price	10	10	15
Rail	Central policy	12.5	12.5	15
	Low price	12	12	12.5
	High price	15	15	17.5
	No carbon price	10	10	10
Aviation	Central policy	modelled	modelled	25
	Low price	modelled	modelled	22.5
	High price	modelled	modelled	27.5
	No carbon price	modelled	modelled	20

4.1.5 CONSTRAINTS ON THE DEPLOYMENT OF ALTERNATIVE FUEL INFRASTRUCTURE

Whilst ESM largely determines the uptake of alternative fuels on the basis of cost competitiveness, the rate at which alternative fuels can increase their share of the overall fuel mix is controlled by infrastructure constraints. Each fuel has its own unique vehicle and fuel distribution infrastructure requirements and the need to deploy this new infrastructure is the main source of delay in deploying new fuels into the fuel mix.

Natural Gas (LNG/CNG)

Australia has an existing natural gas pipeline network and the technology for compressing or liquefying natural gas is well developed. Although very limited, some public compressed natural gas fuelling stations are available. Alternatively it is assumed home natural gas compression appliances can be purchased. LNG processing and fuelling stations would need to be developed at freight hubs. However, there is no reason to assume this would cause a long term delay.

It is assumed that the supply of natural gas vehicles would be limited for a period. The economics of global vehicle manufacturing facilities results in some delay or lag between when the market signals demand for a new vehicle type, and when manufacturers increase their supply. Demand is expected to be driven by the opportunity to save on fuel costs relative to diesel and petrol. The assumed rate of increase in CNG and LNG vehicles is shown in Table 4-5.

Table 4-5: CNG and LNG vehicle supply assumptions

	2010-2015	2015-2020	After 2020
LNG trucks	1500	3000	unlimited
CNG vehicles	25,000	100,000	100,000 increasing by 10,000 p.a.

Biofuels

ESM includes a wide variety of biofuel feedstocks. Existing agricultural co-product feedstocks such as wheat starch, C-molasses, tallow and waste oil are assumed to be available immediately. A portion of the export fractions of agricultural products such as grain, sugar and canola are also assumed to be available but are generally too high cost to be taken up in the modelling. Collectively these feedstocks are termed "first generation".

Advanced (second and third) generation feedstocks include non-food resources, such as lignocellulose and in-edible biologically derived oils. Lignocellulosic sources include forest and forestry waste, crop stubble and coppice eucalypts. Biologically derived oils include pongamia and algae. Urban waste is another resource which may contain a mix of feedstocks but principally lignocellulose such as construction waste.

No delay is assumed in the availability of first generation feedstocks. However, their supply is limited and, as discussed, some are not economically viable when food prices are high. Advanced generation feedstocks are assumed to be constrained in terms of how quickly they can be deployed for two reasons. The first is that they require new refining infrastructure to be built to accommodate their conversion into transport fuels. Lignocellulose resources are more generally available and there are some high density hot spots around Australia where relatively large plant could be developed. Refining processes and resources for biological oils are more suited to smaller scales. Further complicating the construction of biofuel refining plant is the fact that ideally some new lower cost refining processes need to be piloted, particularly in relation to converting lignocelluloses into hydrocarbon fuels, before being deployed at commercial scale.

The assumptions for refining costs that have been included in the modelling are:

- Gasification/ Fischer-Tropsch: starting at 80c/Lpe (cents per litre of petrol equivalent) reducing by 70 percent over twenty years (partly as a proxy for other prospective lignocelluloses refining processes which are not yet proven, e.g. fast pyrolysis). This is consistent with IEA(2009) projections
- Saccharafication- starting at 22c/Lpe reducing by 25 percent over the next twenty years
- Deoxyhydrogenation – starting at 10c/Lpe reducing by 50% over the next twenty years.

The second constraint to the rate of deployment is that some feedstocks need to be cultivated before they become available. The development of coppice eucalypts as part of mixed farming and forestry systems would need to be planned and developed. No significant supplies currently exist. Similarly for potential biological oil resources such as pongamia and algae, these resources would need to be trialled and developed. In the case of pongamia, plantations would not produce the first oil bearing seeds until 7 years after initial planting.

On the basis of these considerations, the supply constraints shown in Table 4-6 for next generation biofuel feedstocks have been applied in the modelling. For higher carbon price scenarios we increase volume that can be deployed per year and the timing of first refinery production.

Table 4-6: Advanced generation biofuel supply constraints by feedstock group

	Before 2015	2015-2020
Biofuel derived from lignocelluloses	0	1500ML increasing by 200ML p.a.
Biofuel derived from vegetable oils	0	750ML increasing by 200ML p.a.

Given that the modelling generally finds biofuels used in low blends which do not require any additional distribution infrastructure or vehicle fleet changes, no specific biofuel distribution constraints have been applied. The importation of biofuels has not been considered in the modelling.

Synthetic Fuels: gas to liquids (GTL), shale to liquids (STL) and coal to liquids (CTL)

Synthetic production of hydrocarbon fuels, primarily diesel, presents very little challenge from a fuel distribution and vehicle adoption perspective. The fuels produced are generally considered to be of similar quality and can be handled and utilised in existing transport modes without any special infrastructure changes.

Rather, the major constraint to deployment of GTL, STL and CTL is the large non-recoverable investment risk that is presented by a refining project of this type. Due to the nature of the Fischer-Tropsch based refining process, efficient scale for the refining plant is around 1.5 gigalitres per annum. At a capacity development cost of around $2.5/L that equates to a minimum expenditure of around almost $4 billion. Investments of this scale do occur in other sectors of the economy. However, as the fuel market, is driven by oil price movements that are relatively volatile, investment markets may perceive this type of investment as more risky compared to other options in the current financial climate. However, strong international growth forecasts in transport demand and subsequently in transport fuel in the Asian region, where fuel security is given a greater premium, may change the perception of level of risk in and the level of risk tolerance of investors towards these types of investments in the longer term.

To take this potential delay into account, it is assumed that an extended period of around a decade of higher trending oil prices will be required before STL, GTL or CTL refining investment proceeds. Between 2 and 3 years delay is added according to the carbon price. The limited delay reflects the limit impact of carbon pricing on fossil to liquid production costs. Paying a carbon permit or, alternatively, introducing carbon capture and storage would add only $12 or $6/barrel respectively to production costs (Mantripragada and Rubin, 2011).

Table 4-7: Synthetic (STL, GTL and CTL) fuel refining construction constraints

	Before 2020	After 2020
STL, GTL & CTL	0	1500ML increasing by 200ML p.a.

LPG

LPG distribution infrastructure has a high penetration level in Australia. Additionally, LPG vehicles are one of the few alternative fuel vehicles which are manufactured locally. As a consequence there are no constraints imposed on the LPG uptake as a result of infrastructure.

Electric and plug-in electric vehicles

Although electricity is distributed widely via the transmission and distribution system there are significant constraints to electric vehicle uptake due to the need for recharging infrastructure and supply of electric vehicles from the global vehicle market. Throughout the modelling we assume that home recharging is preferred and therefore the need for public recharging infrastructure is not a significant constraint. It is acknowledged, however, that there will need to be alternative solutions for those without off-street parking and it may also be more efficient for the system if off-peak power shifts to the middle of the day while most cars are not at home.

Global electric vehicle supply is assumed to be a limiting factor to 2020. Australia does not have relatively attractive electric vehicle subsidies and so is not a priority market for vehicle manufacturers. It is assumed we are only able to access a fixed share of global electric vehicle supply which is expected to be slow to ramp up in the short term. Note that this constraint is generally not binding in the modelling except in the high carbon price scenario.

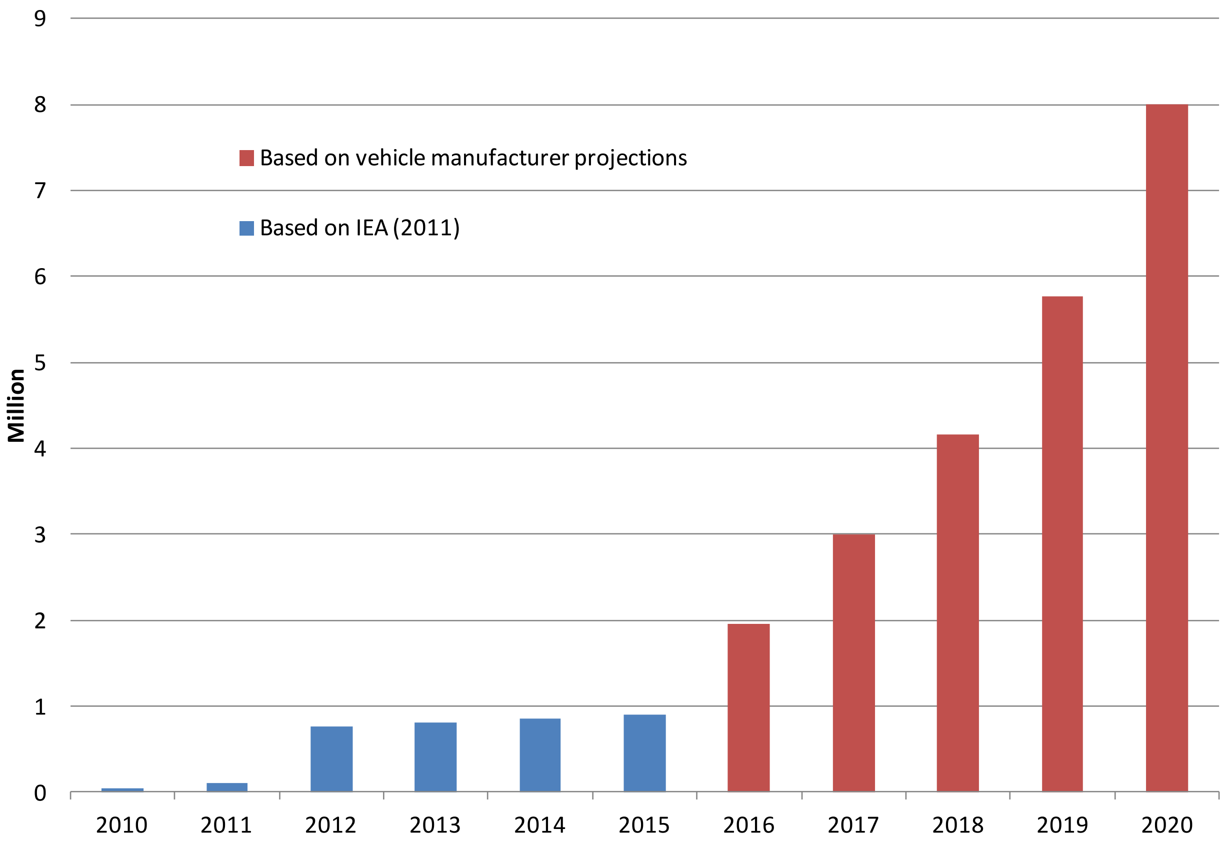


Figure 4-6: Projected global electric vehicle availability

Another issue is that local electricity distribution systems may come under some pressure due to the increased load if electric vehicle uptake reaches a high level. How much of an issue this will become depends a lot on how recharging is managed more generally which at this stage is unknown.

If electric vehicles are charged over several hours (at roughly equivalent to the load of a residential air-conditioner) during periods of low electricity demand they potentially do not impose any additional pressure on the capacity of the network. However, if some charging occurs at faster rates or during times when the electricity load is high then they could present some challenges to existing capacity. The modelling assumes that the former situation occurs and there are no specific constraints to the capacity of the electricity distribution system. Lower charging costs during off-peak times will encourage this outcome.

Hydrogen fuel cell vehicles

Hydrogen is not a fuel that has been widely distributed in Australia. It is typically used in industrial applications where it is manufactured from natural gas reforming on or near the site of use. If natural gas is the primary energy source for hydrogen then the existing natural gas pipeline network is a positive. Similarly, if the source of hydrogen is electricity, via electrolysis, then the existing electricity distribution system is another positive point in favour of hydrogen distribution. Some hydrogen fuel cell vehicle manufacturers have been working towards developing small scale home electrolysis units (Honda, 2011).

However, if new hydrogen distribution systems had to be developed because, for example, it was desirable to manufacture the hydrogen at a central location (e.g. as a co-product of biomass to liquids processes or as a measure to smooth out the generation profile at a wind farm) there are trucking and pipeline systems that could enable that to type of distribution system to be developed.

There have been many studies examining the optimal ways to distribute hydrogen. Mintz et al. (2006) and Yang and Ogden (2007) studied the relative merits of three alternative delivery systems: compressed gas in trucks, liquid gas in trucks and pipelines. Compressed gas trucks were found to be ideal for low consumption markets at a short distance from the hydrogen production site. However, if the consumption at the delivery node was high then pipelines were preferred no matter what the delivery distance was. If the distance was large but the consumption at the delivery site was moderate then liquid gas distribution in trucks was preferred.

Pigneri (2005) compared using local electrolysis to compressed gas trucks and pipelines. He found that there were cost advantages in the strategy of using the electricity grid as the main distribution system, since this avoided building a pipeline that would be under-utilised for many years. However, if the market penetration was above 25 percent the other distribution options were more cost effective.

Cheng and Graham (2009) tested these general findings in a case study of hydrogen distribution in Victoria under a more realistic scenario of gradual adoption of fuel cell vehicles. The modelling results generally supported past conclusions about the relative competitiveness of gas by truck, and liquid by truck and pipeline delivery modes. However, the modelling indicated that pipeline delivery will not be economic during the early stages of market penetration, will reach a point of dominance when demand is significant but at short distance, but may lose significant share of the hydrogen delivery task when new small scale supply fields must be drawn upon as demand increases.

The wide number of distribution options and the ability to combine different options for different primary energy resources and at different stages of fuel cell vehicle adoption indicates there is no basis for constraining hydrogen fuel cell uptake in the modelling on the basis of a lack of existing distribution infrastructure. However, the model does constrain the rate of global fuel cell vehicle supply to Australia. Unlike in the case of electric vehicles, there is far less information regarding the availability of this type of vehicle. Given that fuel cell vehicles use the same electric drive train configuration as fully electric vehicles (carrying fuel cells and hydrogen instead of batteries) we assume that fuel cell vehicles can be supplied at the same rate per annum.

Conventional transport fuels

Petrol and diesel manufactured in the conventional way from oil is assumed to have no limit on its supply. It is noted that oil is one of the very few energy resources that Australia has in limited supply and our petroleum fuel refining capacity is less than our annual consumption. However, it assumed in all scenarios that Australia is able to secure the required amounts of oil for refining or alternatively, petrol and diesel products that have been refined elsewhere in the world.

4.1.6 POLICY ASSUMPTIONS

Under all scenarios it is assumed existing transport polices remain in place. They include fuel excise rates, the NSW Biofuels Act and the LPG Vehicle scheme.

Fuel excise rates and levies

Petrol and diesel have a nominal dollar excise rate of excise of 38.143 c/L since indexation ceased in 2001. Heavy road vehicles are entitled to a fuel tax credit of 38.143 cents per litre. However, they are liable to pay a road user charge of 26.14 cents per litre from July 2013[5] making their effective excise rate equal to the road user charge which is reviewed each year.

Road excise rates applying to alternative transport fuels were re-designed in 2011 and like petrol and diesel the rates are set in nominal dollar terms. Ethanol and biodiesel are liable for excise of 38.143 c/L. However, under the Ethanol Production Grants Program, grants of 38.143 c/L are provided for domestic production of ethanol. In addition, the Energy Grants (Cleaner Fuels) Scheme provides 38.143 c/L grants for the domestic production and import of biodiesel and renewable diesel. These arrangements will continue until at least 30 June 2021[6].

LPG and natural gas were designed to experience a gradual phase in of excise rates based on energy content from 2011-12. As a result, the excise component of these alternative fuels has been increasing but will remain discounted relative to conventional fuels. The phase-in period is to 2015. Ethanol imports also attract a duty of 5 percent. The excise rates for alternative fuels are shown in Table 4-8.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 at the assumed inflation rate of 3.1 percent.

Table 4-8: Assumed excise rates

	LPG	**Natural Gas**	**Biodiesel****	**Ethanol****
	$ per litre	$ per kilogram	$ per litre	$ per litre
2011-12*	0.02500	0.05224	0.38143	0.38143
2012-13	0.05000	0.10448	0.38143	0.38143
2013-14	0.07500	0.15673	0.38143	0.38143
2014-15	0.10000	0.20897	0.38143	0.38143
2015-16	0.12500	0.26122	0.38143	0.38143

* LPG and natural gas rates introduced from 1 December in 2011

** Ethanol and biodiesel excise is in some cases offset by other grants. Under the Ethanol Production Grants Program, grants of 38.143 cents per litre are provided for domestic production of ethanol. The Energy Grants (Cleaner Fuels) Scheme provides 38.143 cents per litre grants for the domestic production and import of biodiesel and renewable diesel

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[5] http://www.comlaw.gov.au/Details/F2013L00990

[6] For simplicity, we assume the policy remains in place indefinitely.

The aviation sector pays an excise of $0.03556 per litre from 1 July 2010 to fund the Civil Aviation Safety Authority (CASA).

New South Wales biofuel mandate

Under the *Biofuel (Ethanol Content) Act 2007*[7], 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:

- 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 was suspended until 1 January 2010)
- Increases the biodiesel mandate to 5% from 1 January 2012 (this requirement has been suspended until sufficient local production is available)
- 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 Biofuels Amendment Act 2012 implemented a policy change to remove the requirement for all regular grade unleaded petrol to be E10 and this came into effect on 29 May 2012.

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.

LPG Vehicle scheme

The LPG vehicle scheme provides $1,000 for the LPG conversion of a used, registered vehicle completed between 1 July 2012 and 30 June 2014. For new vehicles fitted with LPG before first registration $2,000 is provided if completed by 30 June 2014. This includes vehicles fitted with LPG at the time of manufacture, and vehicles fitted with LPG after manufacture but before first registration[8].

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[7] See http://www.biofuels.nsw.gov.au/legislation for further details beyond this summary
[8] http://www.ausindustry.gov.au/programs/energy-fuels/lpgvs/Pages/default.aspx

4.1.7 COMBINED IMPACT OF EXCISE, OIL AND GAS PRICE ASSUMPTIONS

By applying Gargett (2010) we can calculate retail fuel prices from the combined impact of the oil and gas price assumptions and assumed excise changes. These are shown in Figure 4-7 and Figure 4-8. Before we have seen the modelling results in the next part of this report they already tell us a great deal:

- LPG will become less competitive in the short term owing to its movement being assumed to follow the oil price but with a smaller excise buffer to absorb that impact. Its prospects may improve if it can offset this with lower LPG vehicle costs or more efficient LPG engines which have been assumed to some extent
- CNG and LNG could be competitive in the passenger and freight road vehicle markets provided vehicle modifications are low cost such that they do not more than offset the fuel price savings. Higher kilometres vehicle modes will be able to take the most advantage of this widening gap.

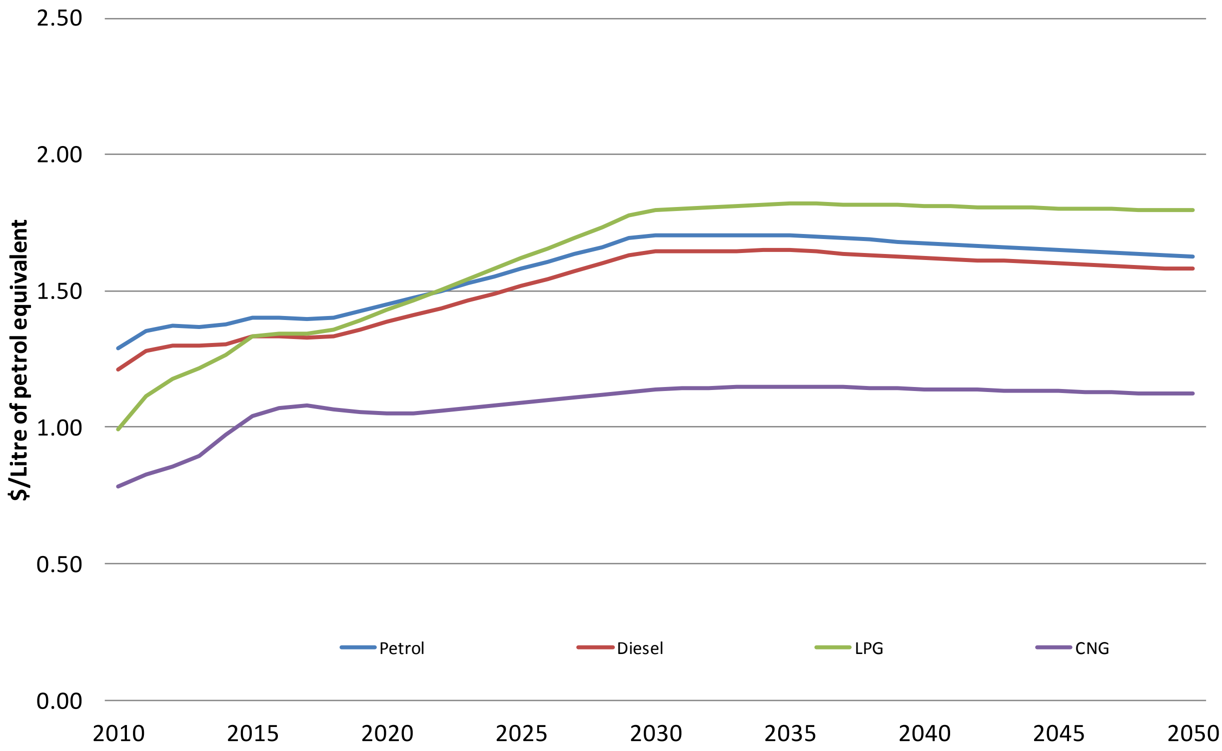

Figure 4-7: Assumed retail fuel prices in petrol equivalent terms, road passenger sector

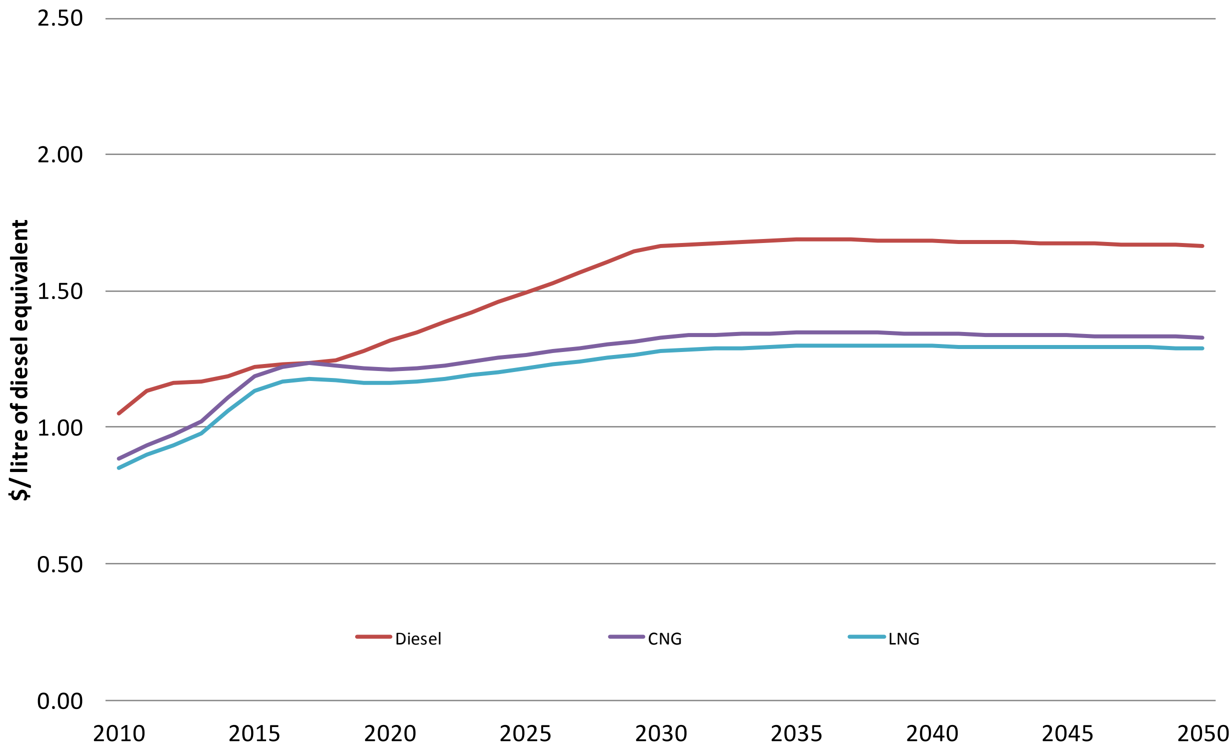

Figure 4-8: Assumed retail fuel prices in diesel equivalent terms, road freight sector

5 Scenario results

This section provides the modelling results for each of the four scenarios modelled:

- **Central policy scenario** — Assumes a world with a 550 ppm stabilisation target and an Australian emission target of a 5 per cent reduction on 2000 levels by 2020 and an 80 per cent reduction by 2050
- **Low price scenario** — The same as the central scenario except that the stabilisation target is reached at a later date such that the carbon price is initially lower but converges by 2030
- **High price scenario** — Assumes a world with more ambitious global action and an Australian emission target of a 25 per cent reduction on 2000 levels by 2020 and an 80 per cent reduction by 2050
- **No carbon price scenario** – the same global context as the central scenario except that Australia does not participate and there is no domestic carbon price.

The results provide projections of the changes in fuel mix across the whole transport sector and the engine technology mix in the road sector.

When interpreting these results it is important to be mindful that the projected outcomes present a combination of factors at play in each scenario – they are not forecasts – they merely represent the outcome that the model projects if all the circumstances within each of the scenarios take place as assumed.

As the scenario assumptions are interplays of future behaviours, technology outcomes and supply factors it is unlikely all of these assumptions will be correct within each scenario. Subsequently, we cannot predict with any certainty which scenario, if any, is more likely to occur in its entirety than another. Those judgments need to be made subjectively by the reader. However, the modelling results are informative in the sense that it helps to highlight the impact that certain drivers could make in a possible future transport sector in Australia.

5.1 Central policy scenario

This scenario imposes a moderate carbon price and a significant oil price increase.

5.1.1 TRANSPORT FUEL MIX

Figure 5-1 shows the projected level of road transport consumption by fuel for the central policy scenario. It shows that at the beginning of the projection period the fuel mix is dominated by petrol (passenger segment) and diesel (commercial and freight vehicles) with some use of liquefied petroleum gas, or LPG, mainly in light commercial vehicles. The limited use of ethanol (blended with petrol in the form of E10) and biodiesel is mainly due to the NSW biofuel mandate.

There is relatively little change in the fuel mix over the next decade with only modest development of some alternative fuels. Small volumes of biodiesel commence a moderate expansion from around 2015. Natural gas, mostly in the form of liquefied natural gas (LNG) for trucks is projected to have the strongest growth, albeit from a small base. Natural gas is taken up in articulated trucks rather than passenger vehicles or smaller trucks because they have the greatest number of kilometres over which to recoup the costs of a modified vehicle through fuel cost savings. For passenger vehicles or smaller trucks the extra costs of accommodating natural gas is not recouped under the model assumptions.

These modest expansions in alternative fuel uptake reflect the fact that, while most alternative fuels are competitive or are expected to be competitive at the projected oil prices, they continue to face considerable constraints across the supply chain. In some cases, vehicles with the appropriate engine for a certain fuel type are not yet in ready supply. In other cases, it is the refining capacity which has long infrastructure development lead times that need to be developed.

An exception to the general trend in consumption of alternative fuels is LPG which is projected to decline. The major reason for this outcome is the projected rise in LPG prices in energy equivalent terms relative to petrol and diesel, for reasons discussed above. The availability of the option to purchase hybrid engines in the road sector has a long run negative influence on the uptake of LPG with market forces favouring petrol and diesel hybrid engines. Once hybrid vehicles become available at lower prices in the long term, road users will have less incentive to use LPG.

Beyond 2020, natural gas, electricity, biofuels and synthetic fuels all increase their share gradually, with the use of natural gas in heavy vehicles continuing its growth. Beyond 2020, there is also mild electrification of the fleet.

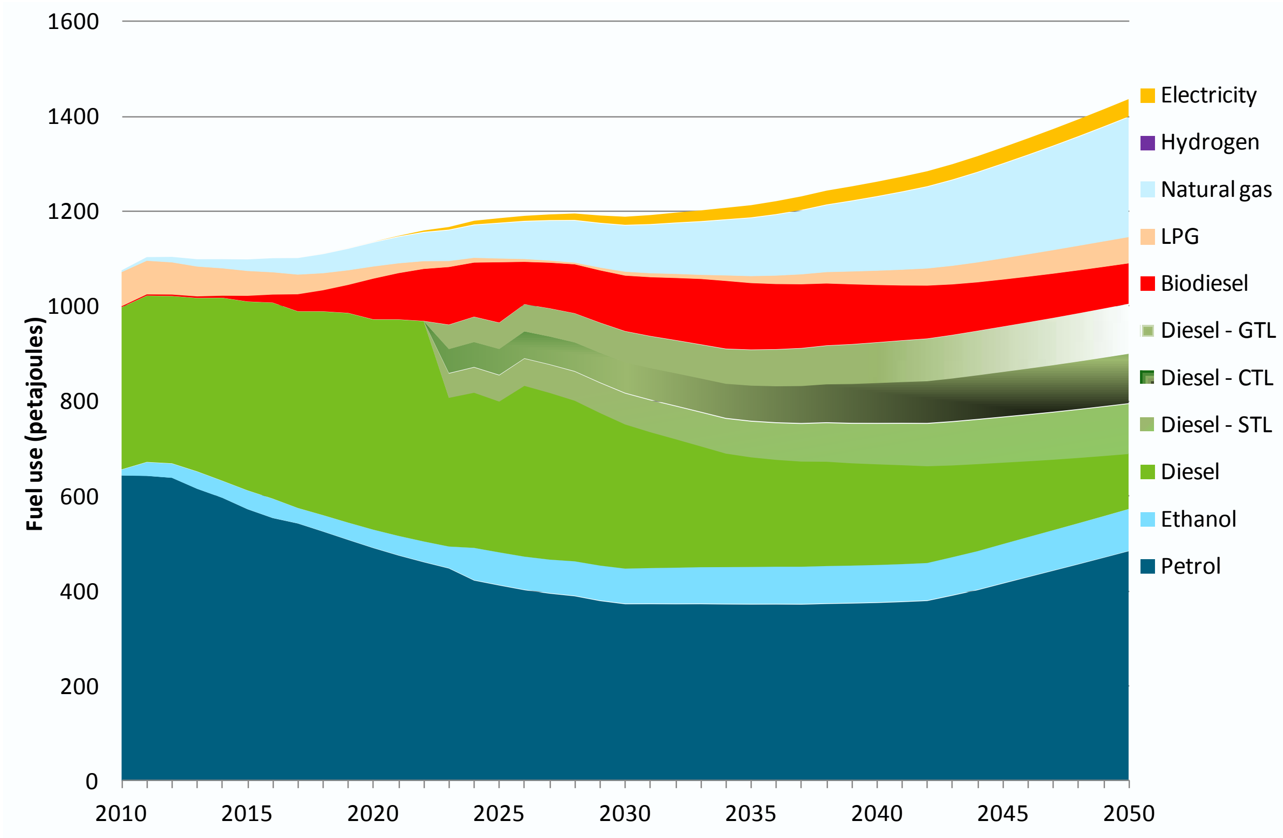

Figure 5-1: Projected road transport fuel consumption by fuel under the central policy scenario

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 LNG in other rigid trucks and articulated trucks. LNG provides a modest reduction in greenhouse gas emissions compared to diesel. However, it is mainly taken up as a cost saving measure with or without a carbon price.

The passenger and light commercial sectors 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 by international vehicle suppliers.

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 making it more attractive to support this vehicle type in Australia.

With oil prices increasing throughout the projection period, the increased supply of low emission alternative fuels (and their infrastructure) is taken up by consumers.

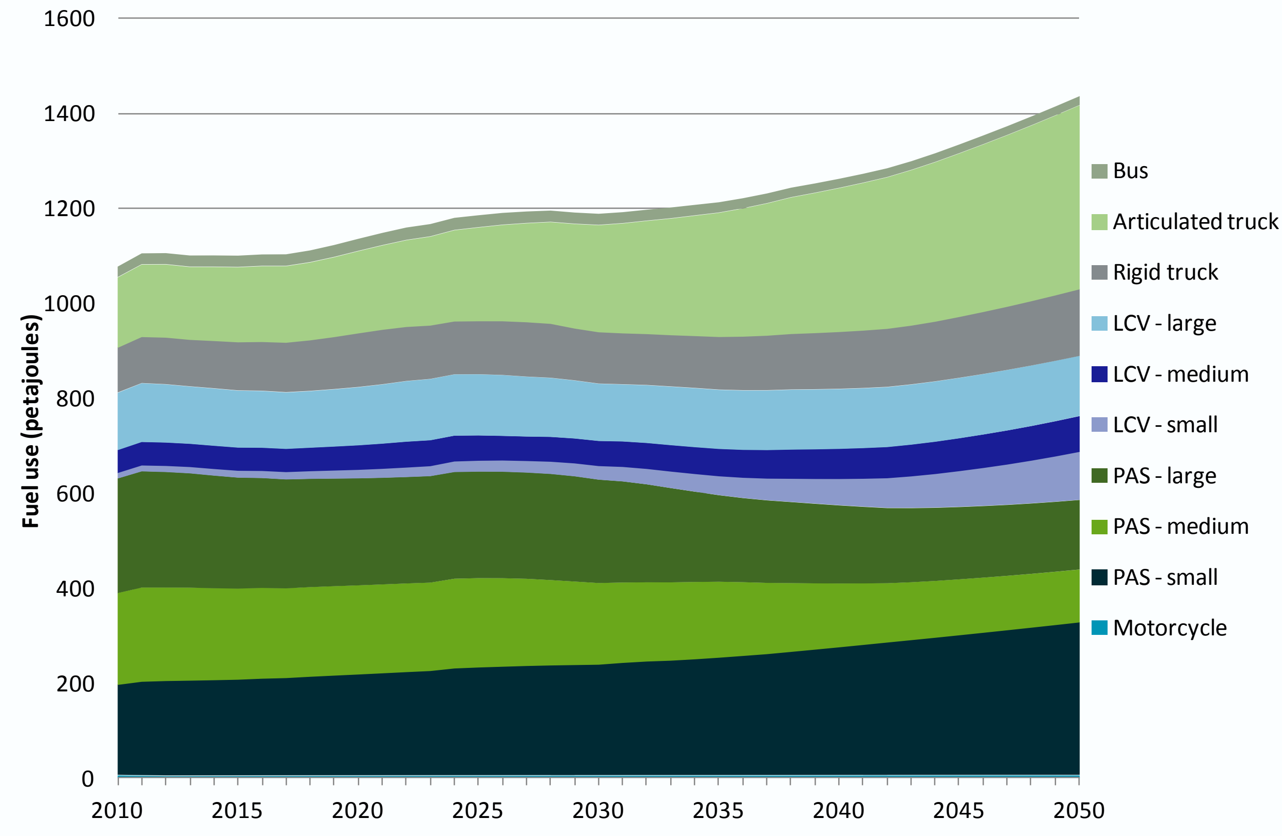

Figure 5-2: Road transport fuel consumption by mode under the central policy scenario

Figure 5-2 shows road transport fuel consumption by mode. Most notable is the continued high growth in road freight and use of lower density fuels (biodiesel and natural gas) leading to significant increase in fuel use for articulated trucks. The growth in fuel use in rigid trucks and buses is checked by a mild degree of hybridisation and electrification of rigid trucks and buses in urban areas. The imposed assumption of increased preferences for smaller vehicles is also evident with fuel use in small passenger and light commercial vehicles increasing over time with commensurate declines in fuel consumption of larger vehicles. This is attenuated by take up of hybrid, plug-in hybrid and some fully electric vehicles in the medium and large passenger and light commercial vehicle segments.

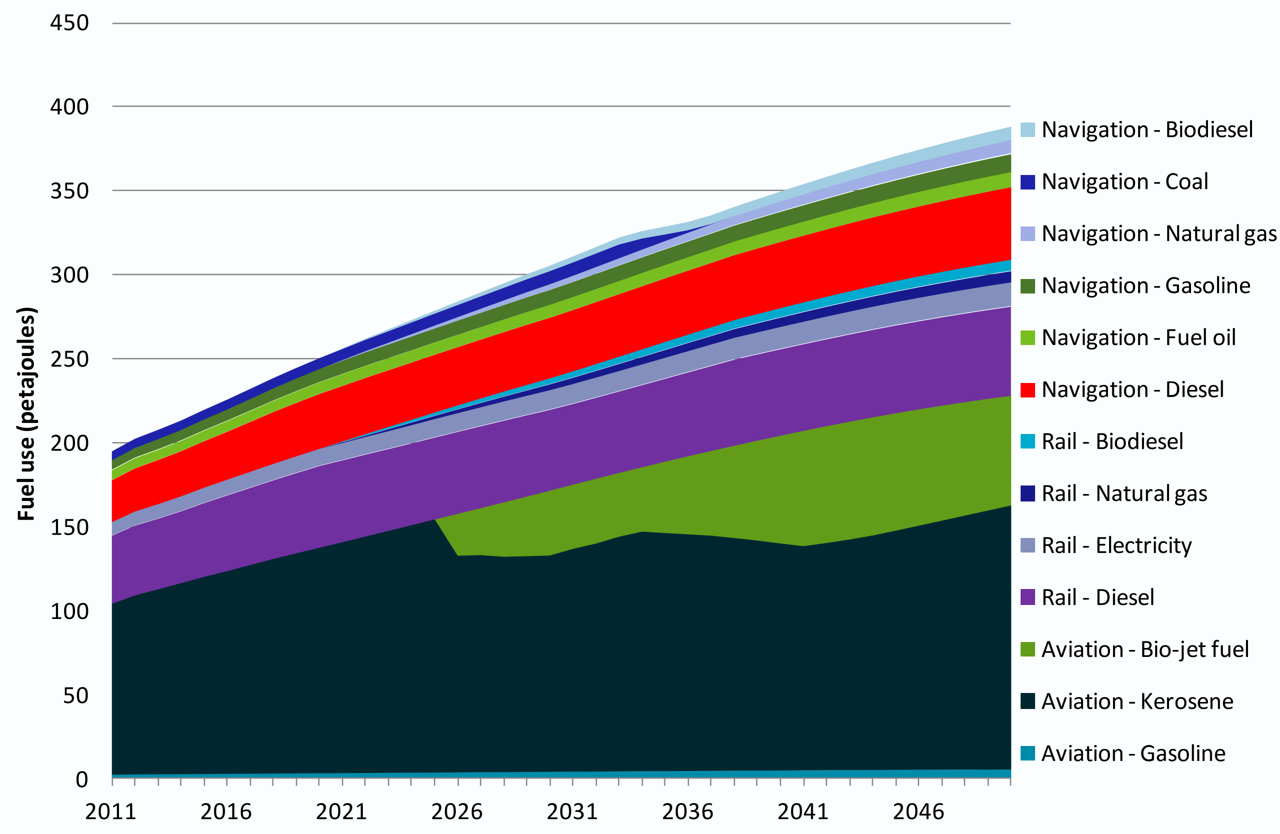

Figure 5-3: Non-road transport fuel consumption by fuel and mode under the central policy scenario

Figure 5-3 shows the projected level of non-road transport consumption by fuel and mode (domestic navigation, rail and domestic aviation) for the central policy scenario. It shows that at the beginning of the projection period the fuel mix is dominated by diesel in navigation and rail, and kerosene in aviation. Aviation is the largest consumer of fuel accounting for around half of non-road transport fuel consumption.

There is relatively little change in the fuel mix over the next decade with only modest uptake of biodiesel and natural gas in rail and navigation. The main change over the projection period is the take up of bio-derived jet fuel by aviation around 2025. Although the aviation sector has other options to reduce its fuel use in response to a carbon price (utilisation of advanced aircraft, fuel conservation and improved airspace management), over the medium- to long-term the take up of low emission jet fuel is the only option for significant emissions reductions given the projected growth in demand. By 2050, bio-derived jet fuel is around 30 per cent of domestic aviation fuel consumption.

5.1.2 ROAD SECTOR ENGINE MIX

Figure 5-4 shows the engine type in road kilometres travelled for the central policy scenario. Out to 2020, the dominance of internal combustion vehicles is expected to continue, reflecting the turnover rate of the vehicle stock and the expected efficiency improvements in conventional vehicles. Hybrid, electric and plug-in electric vehicles start to become an economically viable option just prior to 2020. Fast adopters have done and will continue to take up these technologies before this time. However, this is the point where ESM has determined it will be a cost effective choice for the majority. Beyond 2025, hybrids dominate vehicle sales with increased uptake of plug-in hybrid and fully electric vehicles.

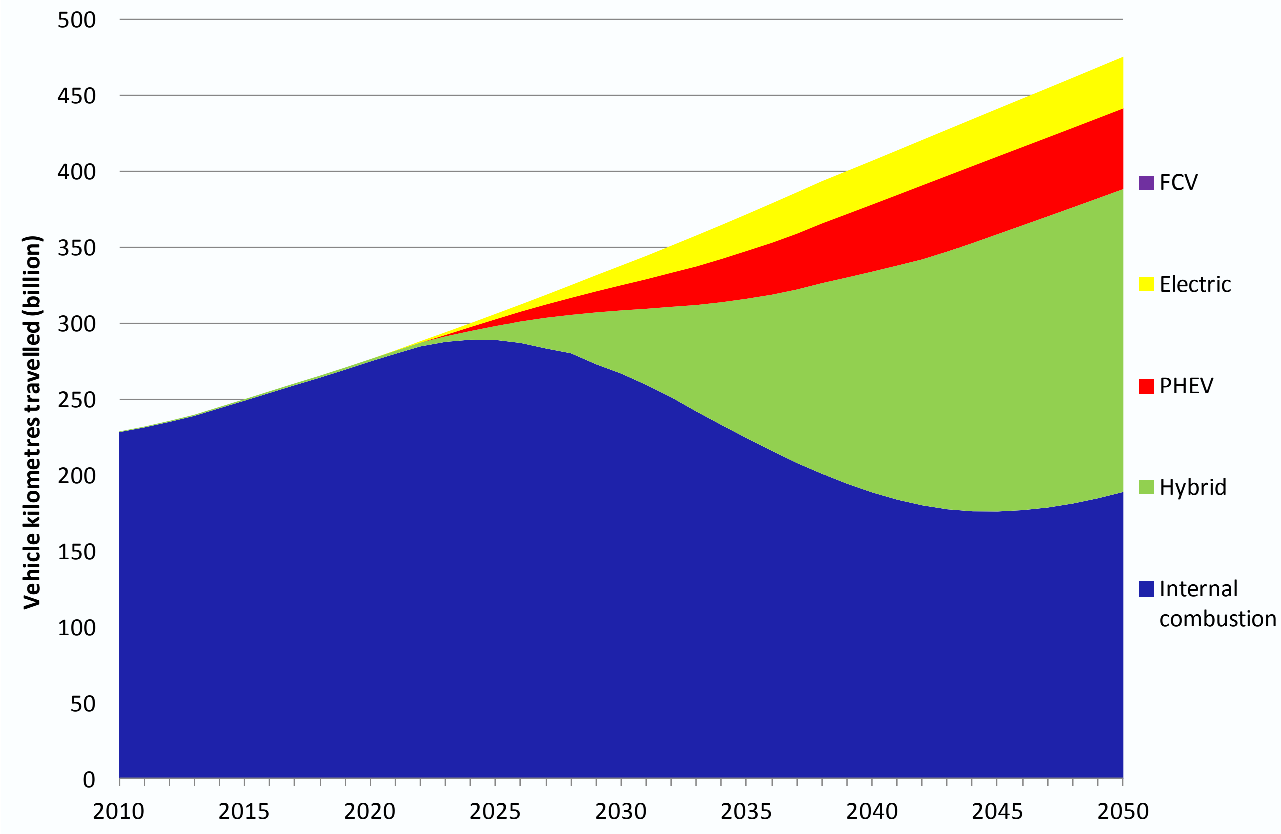

Figure 5-4: Engine type in road kilometres travelled, central policy scenario

The carbon price signal in the heavy vehicle sector is assumed lead to support a moderate level of electric vehicle availability with spill-over effects for electric vehicle uptake more broadly across the light road vehicle sector. By 2050, electricity fuels around 17 per cent of all road travel.

5.1.3 GREENHOUSE GAS EMISSION PROJECTIONS

Figure 5-5 shows the greenhouse gas emissions by mode for the road transport sector under the central policy scenario. The decline in emissions to 2025 reflects the uptake of lower emission gaseous fuels (biodiesel, ethanol blended petrol, LPG and natural gas) and the greater fuel efficiency of new vehicles in the fleet. The sharp increase in emissions around 2025 reflects the uptake of synthetic diesel (coal to liquids, gas to liquids and shale to liquids) reflecting the cost competiveness of these 'drop-in' fuels and as increasing amounts of bio-derived jet fuel are demanded by the aviation sector. Around 2030, road sector emissions begin to increase, largely reflecting the flattening out of oil prices at this time reducing the marginal benefit of increasing hybridisation/electrification of the vehicle fleet.

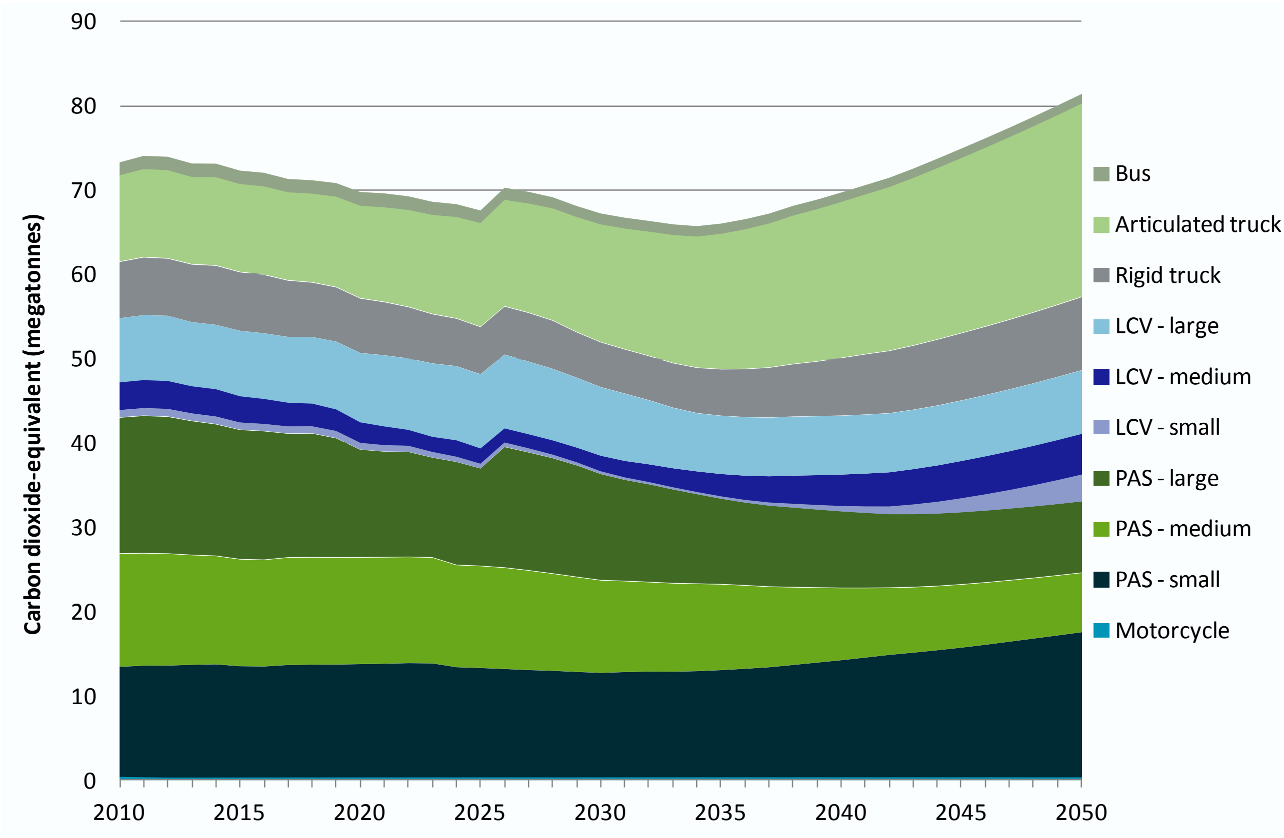

Figure 5-5: Road transport greenhouse gas emissions by mode under the central policy scenario

Figure 5-6 shows the projected greenhouse gas emissions for the non-road transport sector under the central policy scenario.

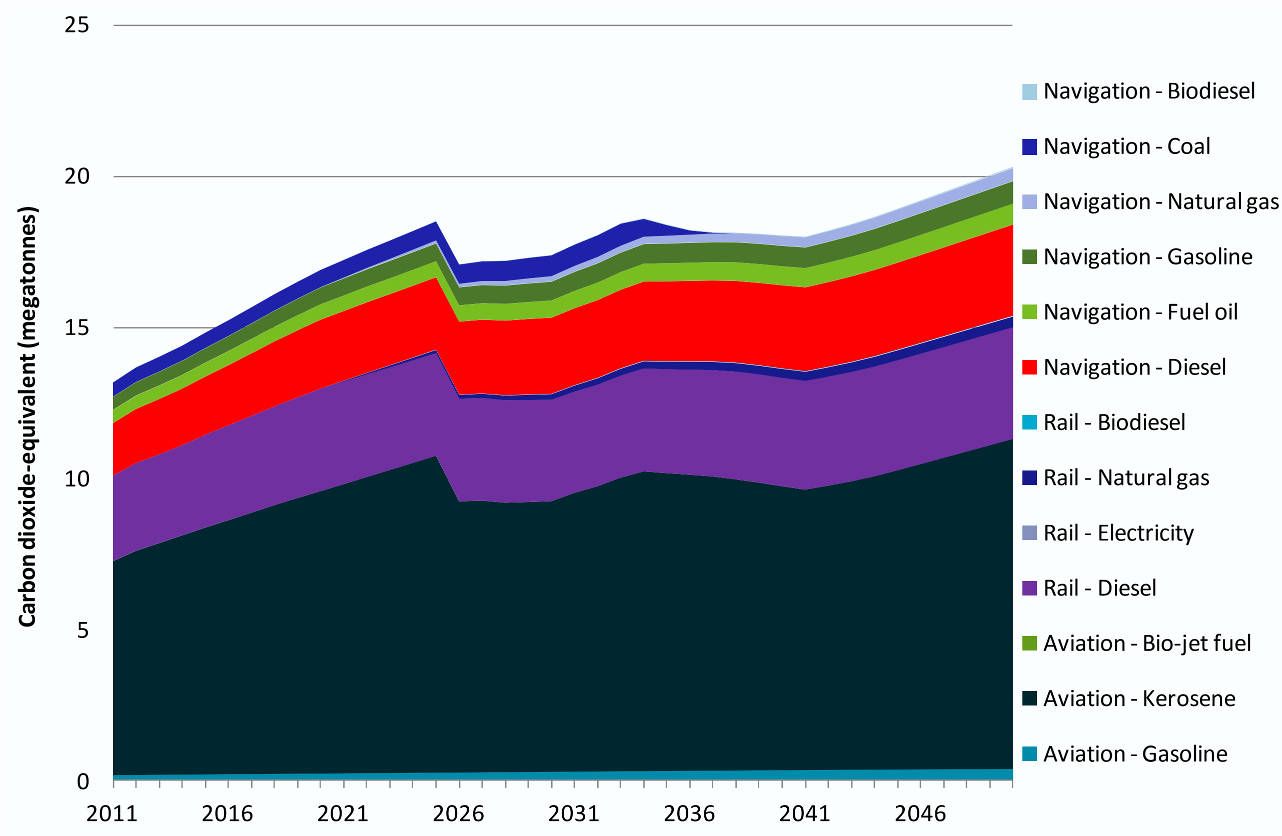

Figure 5-6: Non-road transport greenhouse gas emissions by mode under the central policy scenario

Clearly evident in Figure 5-6 is the impact of bio-derived jet fuel around 2025, as the aviation sector adopts low emission fuels in response to an increasing carbon price. The assumed phase-out of coal in navigation in Queensland around 2035 is also noticeable.

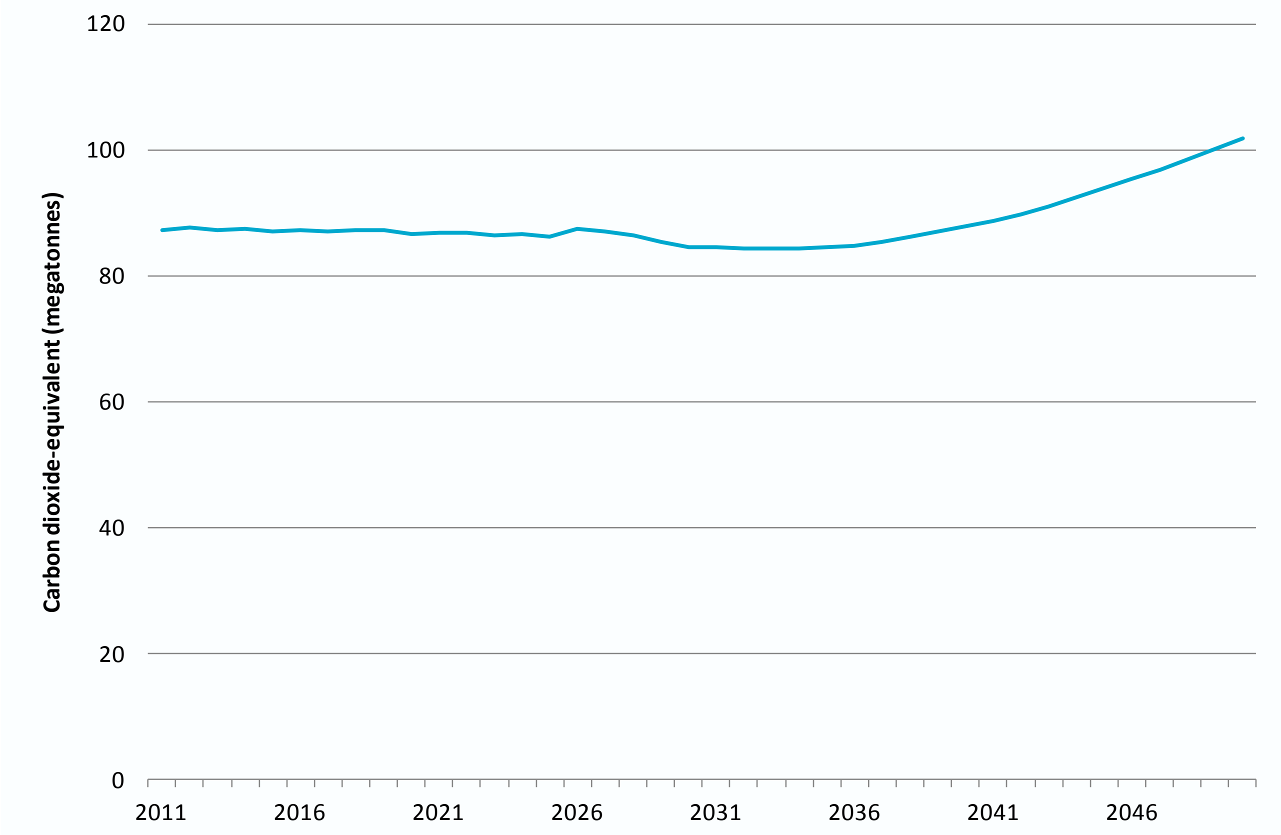

Figure 5-7: Transport sector greenhouse gas emissions under the central policy scenario

Figure 5-7 shows that out to around 2030 the declining greenhouse gas emissions in the road transport sector is largely offset by increasing greenhouse gas emissions in the non-road transport sector, particularly aviation.[9] However, beyond 2030, the continued growth in activity levels, and the flattening oil price in combination with a moderate carbon price, reduces the marginal benefit of accelerated uptake of low emission fuels and alternative drivetrain vehicles.

[9] For greenhouse gas emission calculations, CSIRO uses the AR2 global warming potentials (21 for CH_4 and 310 for N_2O).

5.2 Low carbon price scenario

This scenario imposes a low carbon price initially increasing to a moderate price signal from 2030 onwards and a significant increase in oil prices.

5.2.1 TRANSPORT FUEL MIX

Figure 5-8 shows the projected level of road transport consumption by fuel for the low carbon price scenario. In the near-term, the projected fuel mix is very similar to that under the central policy scenario. The main point of departure is that low emission fuels are less competitive under this carbon price regime, resulting in greater consumption of crude-based diesel in the medium-term at the expense of less biodiesel from 2015 onwards. As carbon prices under this scenario start to converge from 2030 onwards, and assuming the same oil price trajectory, there is also convergence in the fuel mix towards 2050.

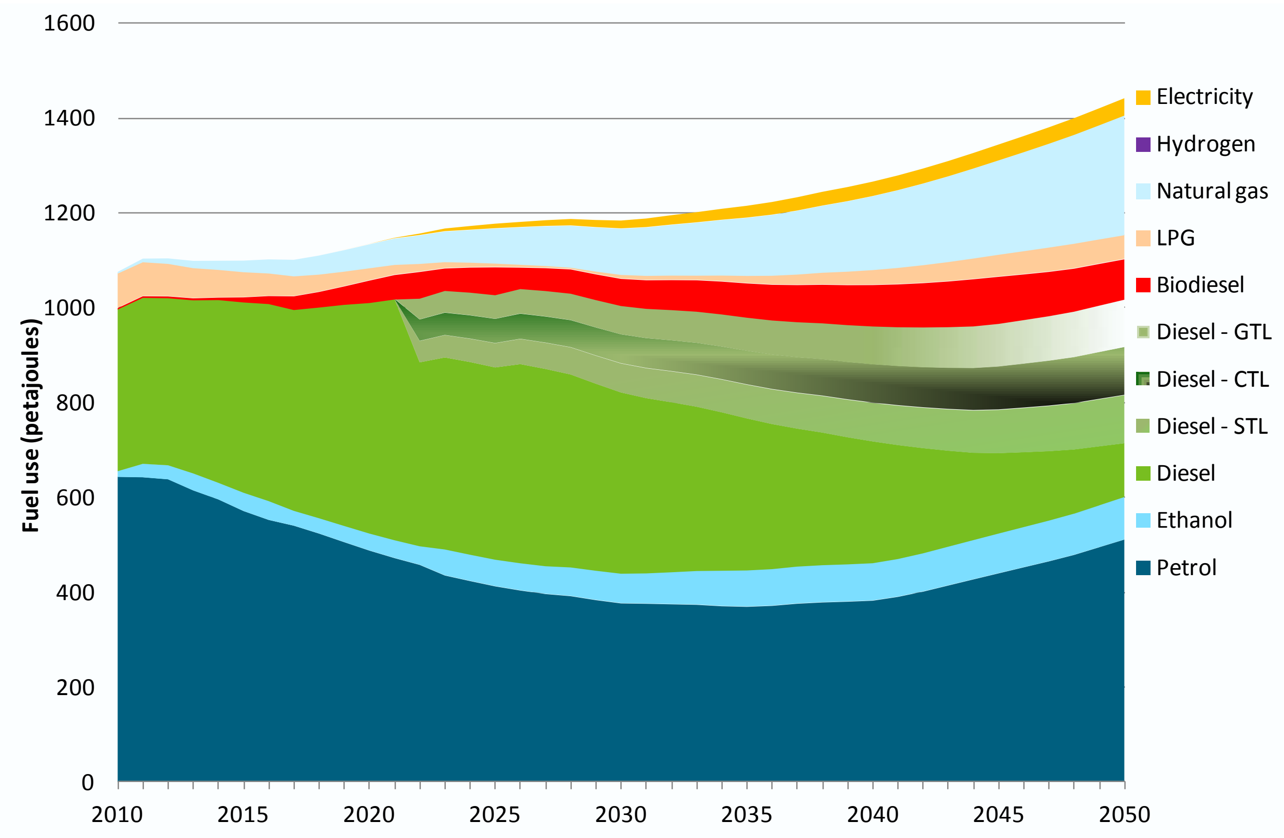

Figure 5-8: Projected road transport fuel consumption by fuel under the low carbon price scenario

The road transport fuel consumption by mode under this scenario is nearly identical to that in the central policy scenario.

Figure 5-9 shows the projected level of non-road transport consumption by fuel and mode (domestic navigation, rail and domestic aviation) for the low carbon price scenario. The main difference to the central policy scenario is that the uptake of bio-derived jet fuel is delayed reflecting the combined effect of oil prices and lower carbon prices reducing the incentive for low emission jet fuel.

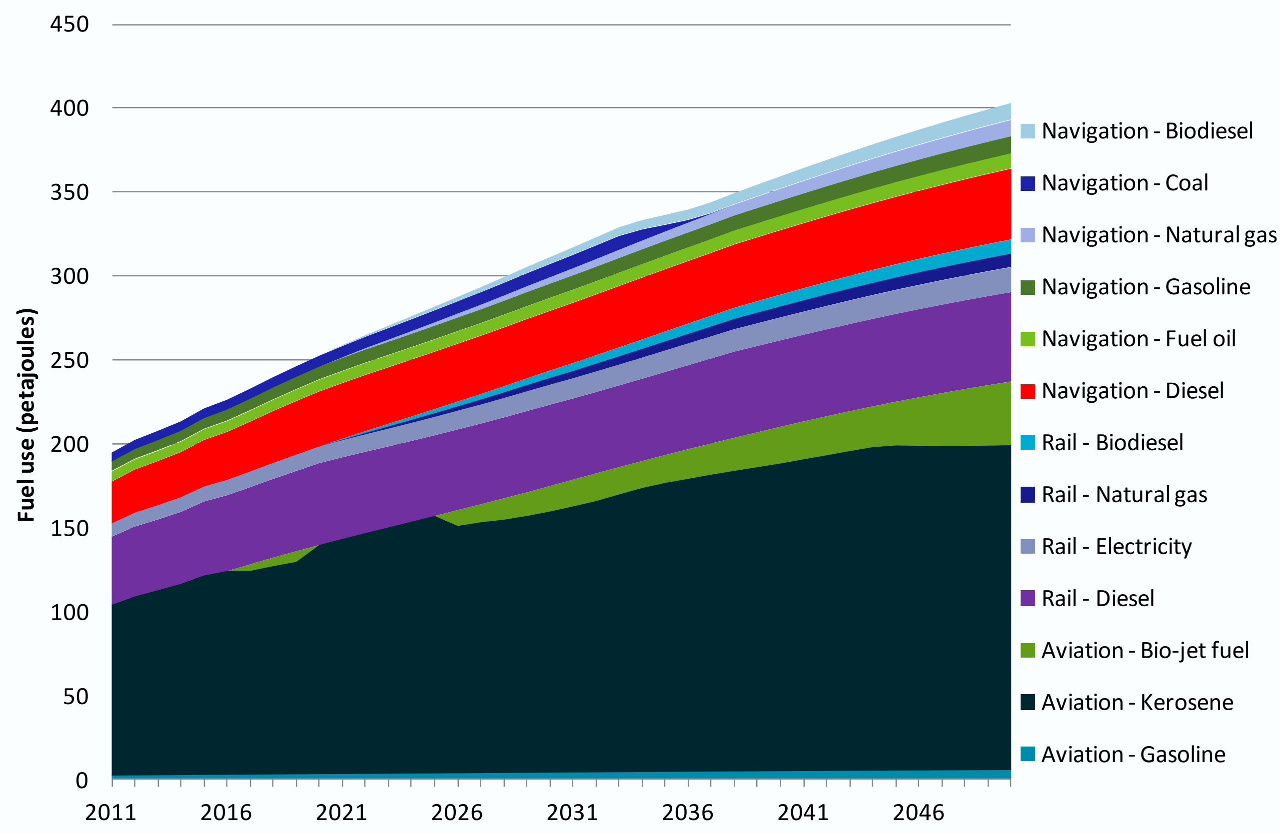

Figure 5-9: Non-road transport fuel consumption by fuel and mode under the low carbon price scenario

5.2.2 ROAD SECTOR ENGINE MIX

Figure 5-10 shows the engine type in road kilometres travelled for the low carbon price scenario. The impact of the lower carbon price trajectory is a slight delay in the uptake of alternative drivetrain vehicles, mainly in the form of hybrids and plug-in hybrid electric vehicles.

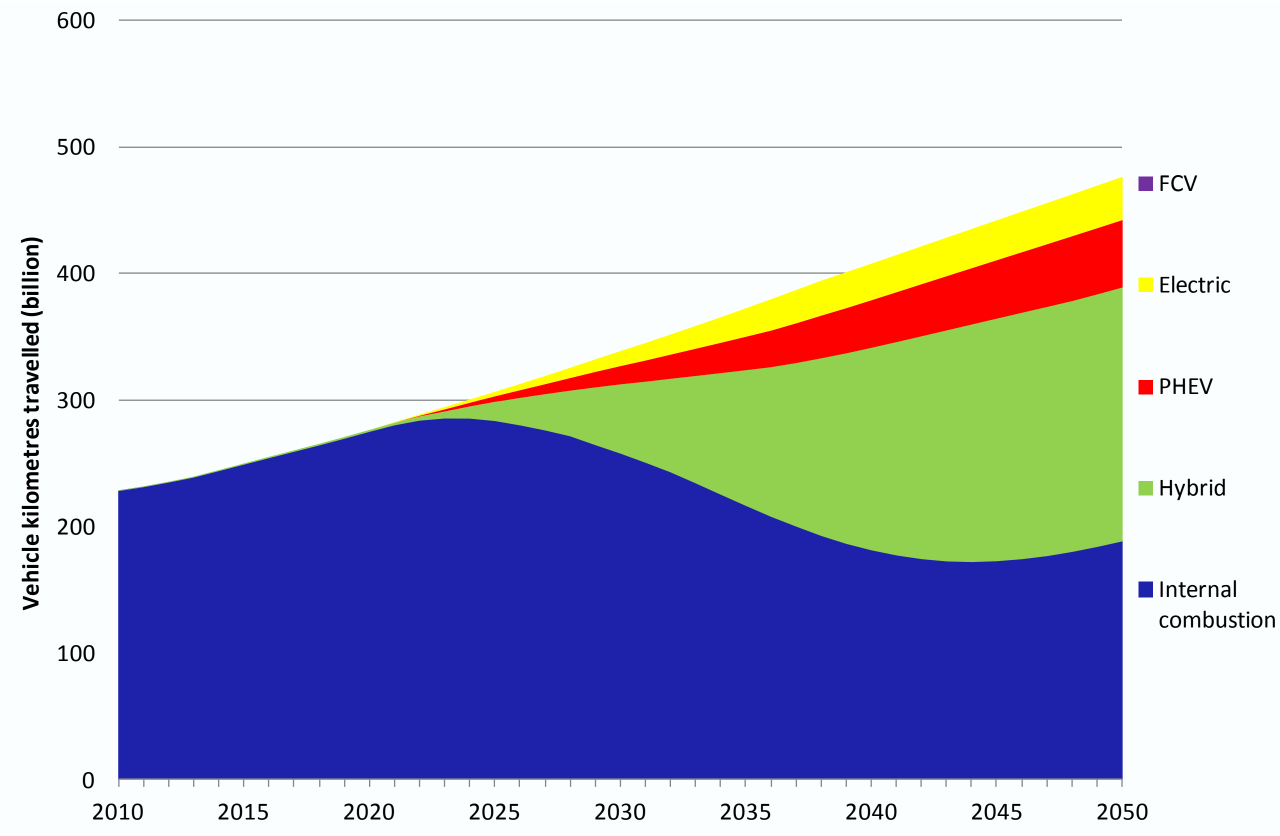

Figure 5-10: Engine type in road kilometres travelled, low carbon price scenario

5.2.3 GREENHOUSE GAS EMISSION PROJECTIONS

Figure 5-11 shows the greenhouse gas emissions by mode for the road transport sector under the low carbon price scenario. The reduced carbon price signal in the near-term reduces the uptake of low emission fuels, particularly biodiesel, resulting in a more muted decline in greenhouse gas emissions to 2025 when compared to the central policy scenario. As a result, the uptick in emissions from synthetic diesel use around 2025 is less noticeable in this case. Beyond 2030, the convergence of oil and carbon prices to that of the central policy scenario, results in very similar emission levels by 2050.

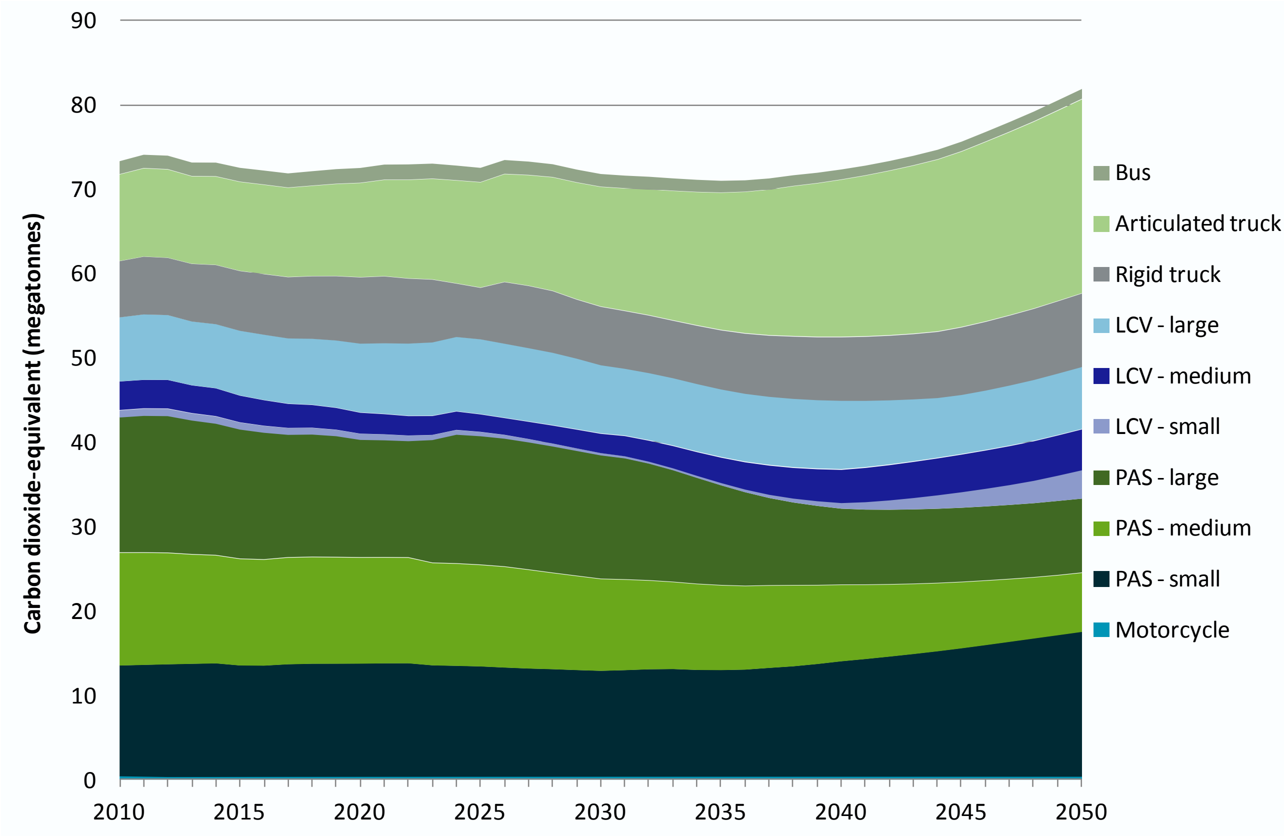

Figure 5-11: Road transport greenhouse gas emissions by mode under the low carbon price scenario

For the non-road transport sector (Figure 5-12), largely reflective of the fuel use, the lower uptake of bio-derived jet fuel means that greenhouse gas emissions are greater than that of the central policy scenario.

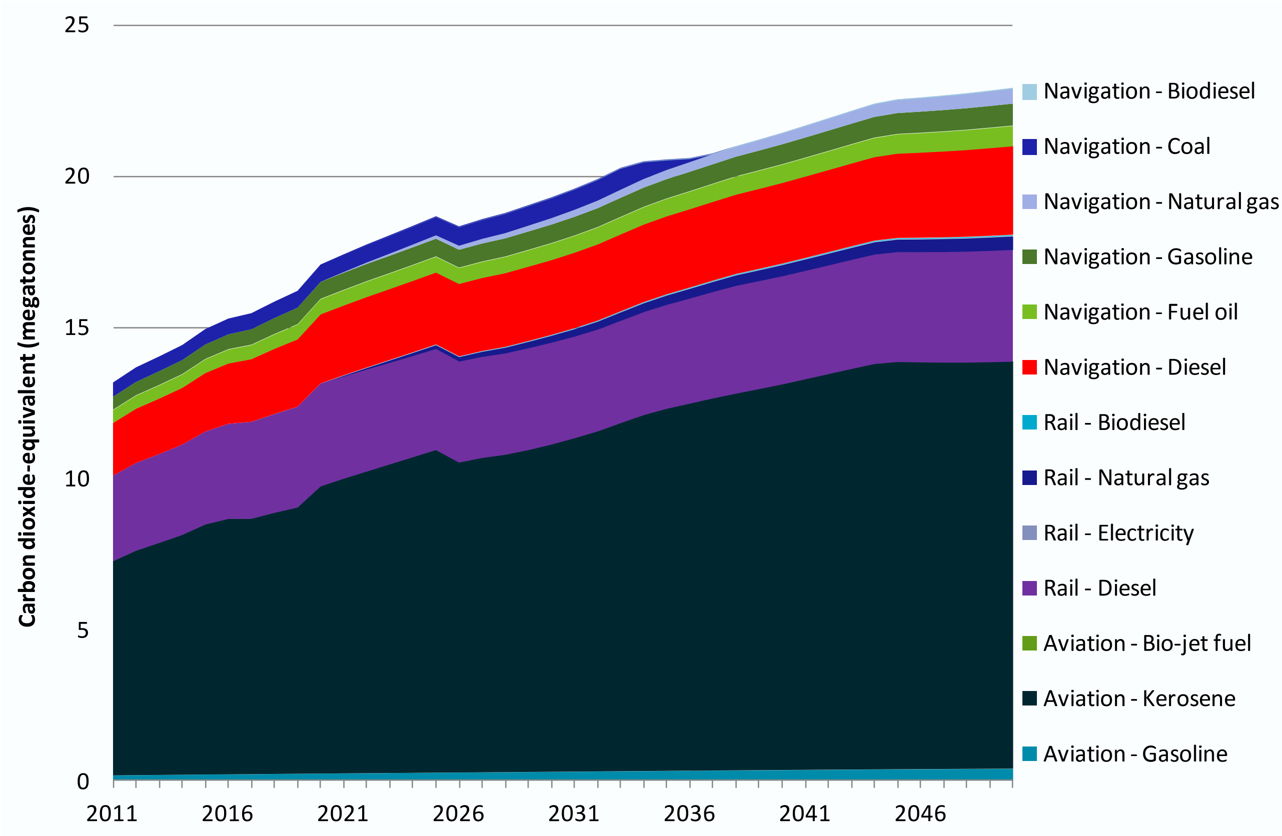

Figure 5-12: Non-road transport greenhouse gas emissions by mode under the low carbon price scenario

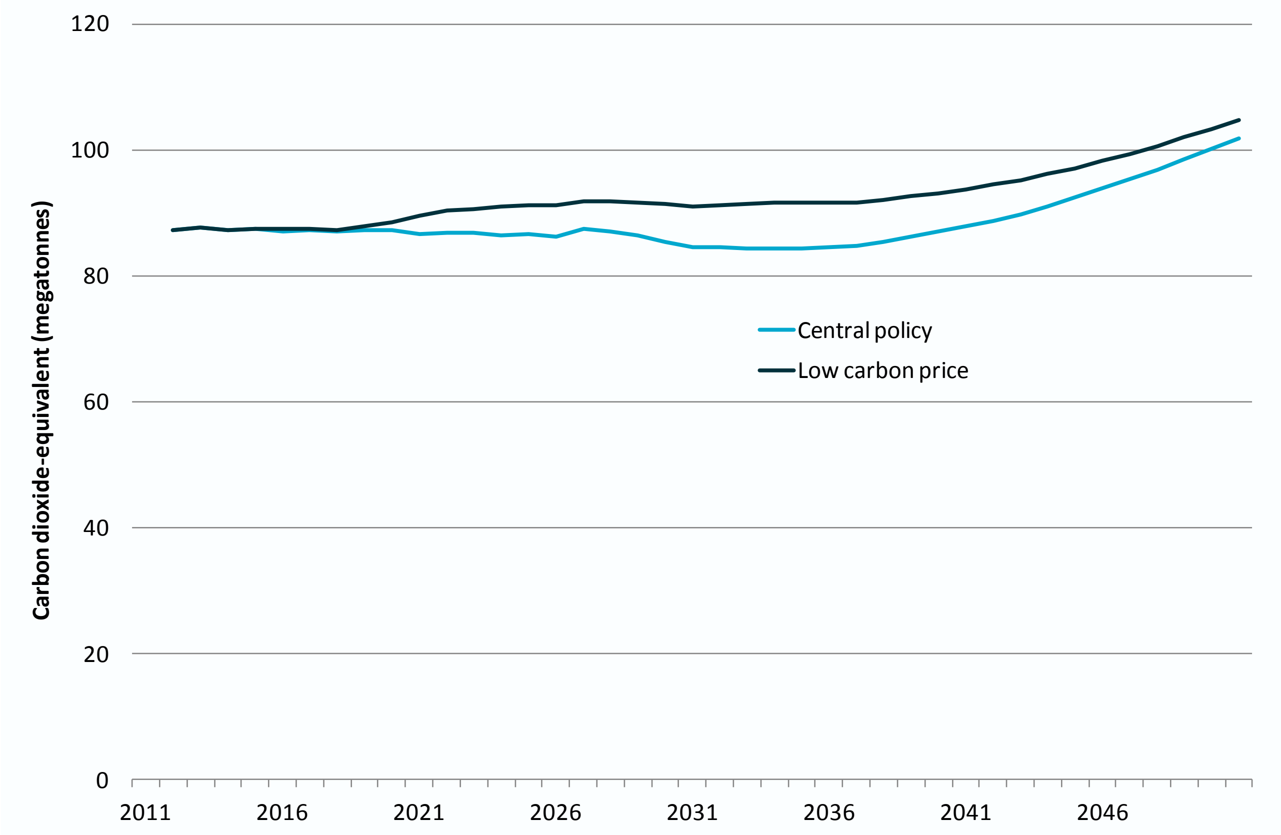

Figure 5-13: Transport sector greenhouse gas emissions under the low carbon price and central policy scenarios

The net effect is that transport sector greenhouse gas emissions are higher in the low carbon price scenario relative to the central policy scenario (Figure 5-13) from around 2015, with the difference at its greatest around 2035 (around 7 Mt higher), then a convergence in emissions towards 2050. At 2050, greenhouse gas emissions are around 3 Mt greater in the low carbon price scenario.

5.3 High carbon price scenario

This scenario imposes a high carbon price and a significant increase in oil prices.

5.3.1 TRANSPORT FUEL MIX

Figure 5-14 shows the projected level of road transport consumption by fuel for the high carbon price scenario. In the near-term, the projected fuel mix is very similar to that under the central policy scenario but at a lower level. The main point of departure is that low emission fuels are more competitive under this carbon price regime, resulting in reduced consumption of crude-based diesel in the medium-term and greater use of biodiesel and natural gas. The lower level of fuel consumption in the near-term mainly reflects the greater uptake of hybrid vehicles, prior to more significant uptake of electricity as a transport fuel. The increased use of petrol in the last decade of the projection period reflects growth in passenger vehicle demand outpacing further adoption of petrol saving vehicle electrification.

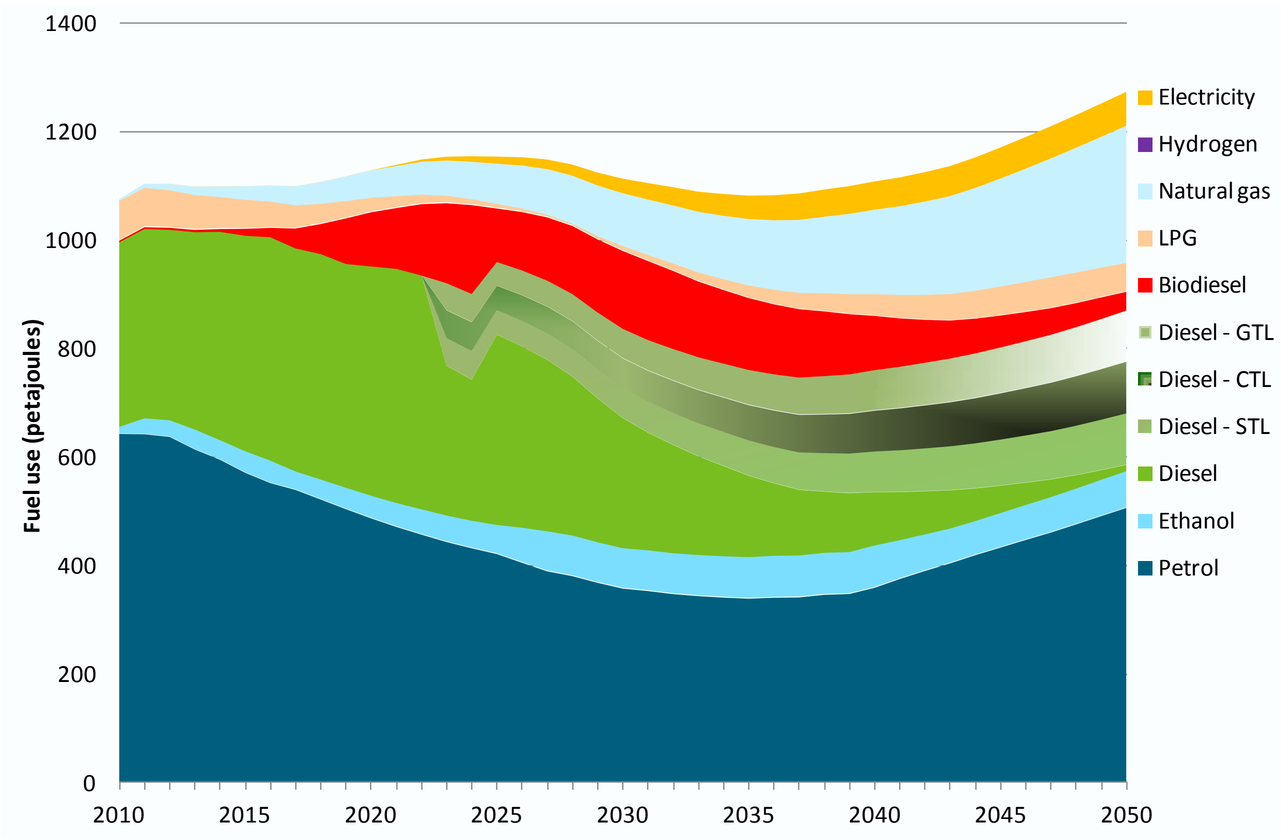

Figure 5-14: Projected road transport fuel consumption by fuel under the high carbon price scenario

Another notable feature is the reduced use of biodiesel in the road sector in the last ten years of the projection period. Figure 5-15 shows that this is the result of ‘competition’ from the aviation sector for low emission fuels in the form of bio-derived jet fuel. By 2050, bio-derived jet fuel accounts for 40 per cent of domestic aviation fuel consumption.

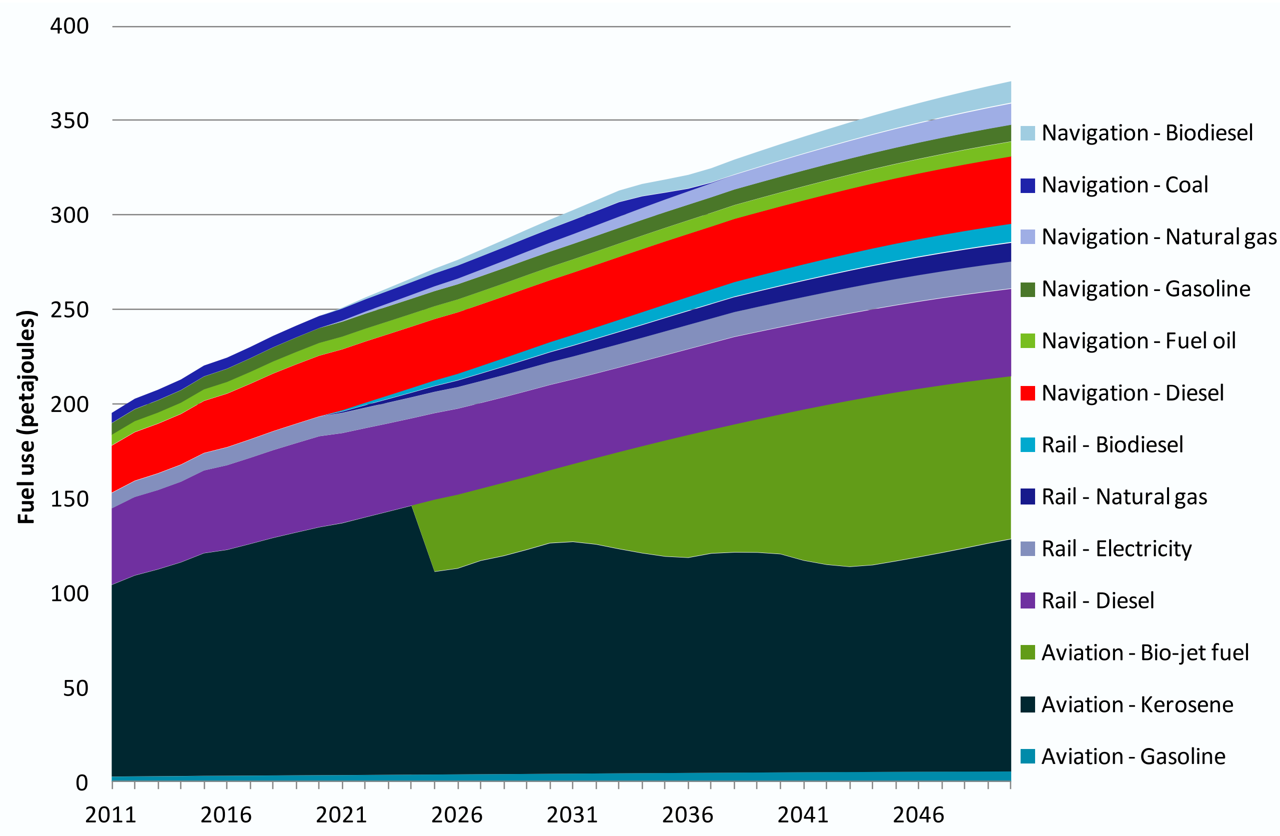

Figure 5-15: Non-road transport fuel consumption by fuel and mode under the high carbon price scenario

5.3.2 ROAD SECTOR ENGINE MIX

Figure 5-16 shows the engine type in road kilometres travelled for the high carbon price scenario. The stronger carbon price signal under this scenario leads to greater uptake of alternative drivetrain vehicles especially plug-in hybrid electric and fully electric vehicles. By 2050, electricity fuels around a third of all road kilometres travelled, increasing the demand for electricity by 17 TWh.

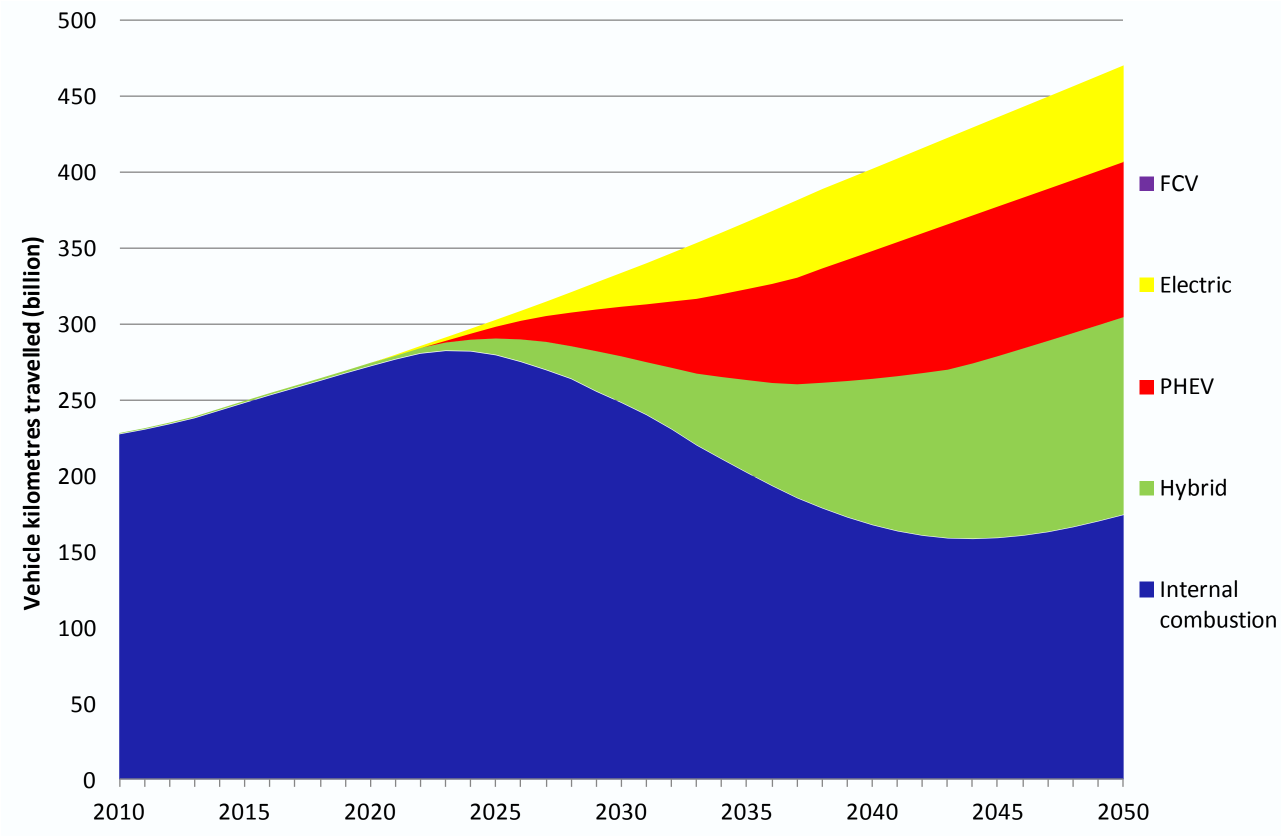

Figure 5-16: Engine type in road kilometres travelled, high carbon price scenario

5.3.3 GREENHOUSE GAS EMISSIONS

Figure 5-17 shows the greenhouse gas emissions by mode for the road transport sector under the high carbon price scenario. It shows that the stronger carbon price signal results in declining emissions to around 2035. Beyond 2035, continued demand growth, the flattening out of oil prices, and reduced availability of biodiesel to the road sector results in rising emissions to 2050. Road sector greenhouse gas emissions in 2050 are around 73 Mt, similar to their current level.

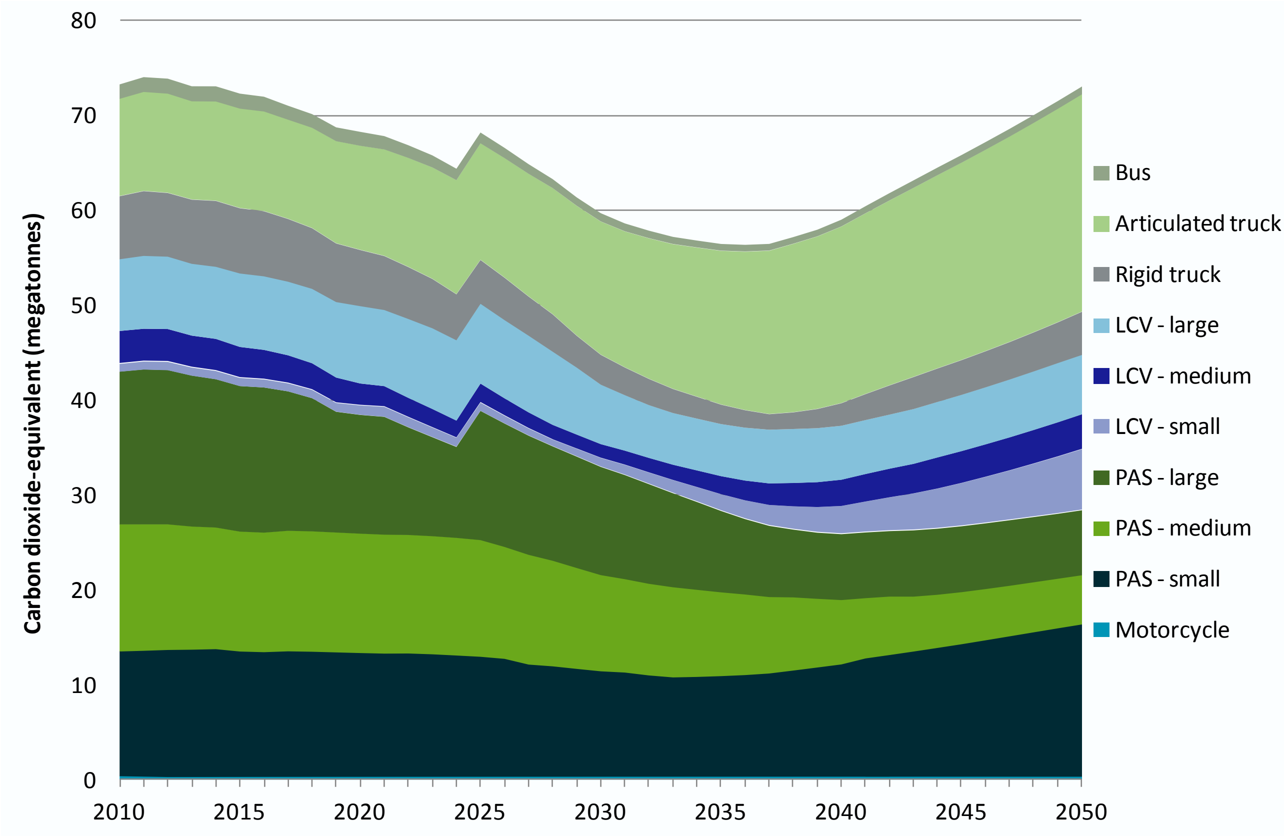

Figure 5-17: Road transport greenhouse gas emissions by mode under the high carbon price scenario

For the non-road transport sector (Figure 5-18), largely reflective of the fuel use, the greater uptake of bio-derived jet fuel in domestic aviation, natural gas and biodiesel in navigation and rail, and assumed improvements in fuel efficiency, means that non-road sector greenhouse gas emissions are lower than that of the central policy scenario by around 3 Mt by 2050.

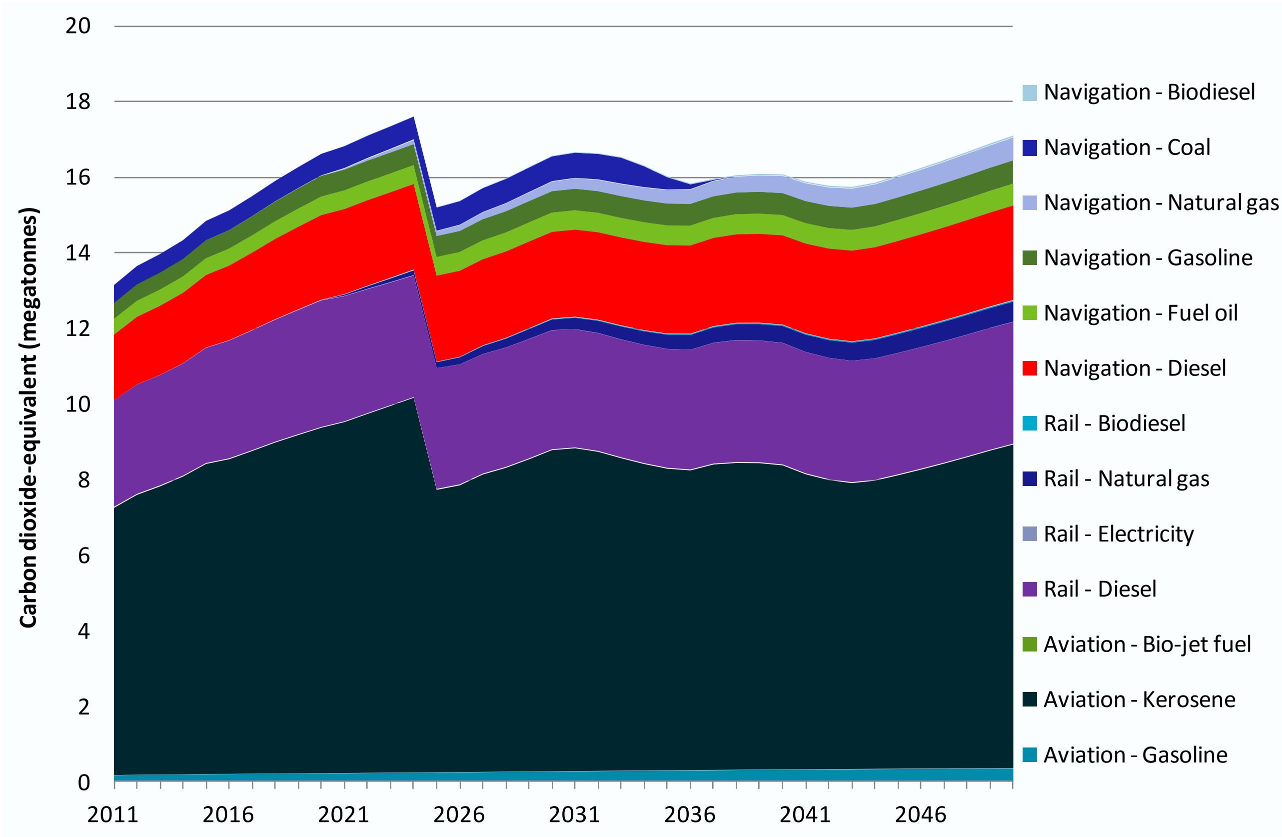

Figure 5-18: Non-road transport greenhouse gas emissions by mode under the high carbon price scenario

The net effect is that transport sector greenhouse gas emissions are lower in the high carbon price scenario relative to the central policy scenario (Figure 5-19) from around 2015, with the difference at its greatest around 2038 (around 13 Mt lower), then a convergence in emissions towards 2050. At 2050, greenhouse gas emissions are around 11 Mt lower in the high carbon price scenario.

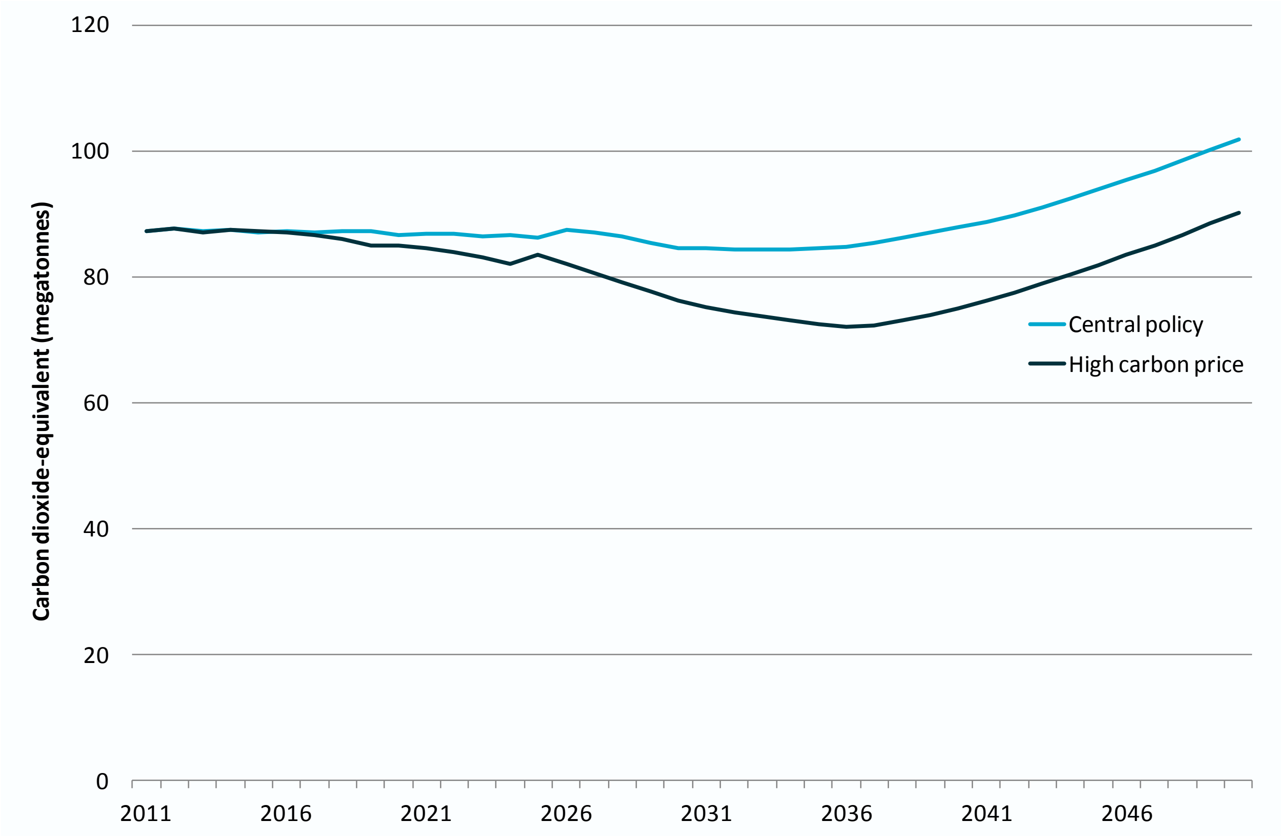

Figure 5-19: Transport sector greenhouse gas emissions under the high carbon price and central policy scenarios

5.4 No carbon price scenario

This scenario does not impose a carbon price but includes a significant increase in oil prices

5.4.1 TRANSPORT FUEL MIX

Figure 5-20 shows the projected level of road transport consumption by fuel for the no carbon price scenario. It shows that the uptake of low emission fuels in the form of biodiesel, ethanol and electricity are less than that under the central policy scenario. The volume of fuel use is also much greater over the projection period reflecting increased activity levels and lessened degree of hybridisation/electrification of the road fleet.

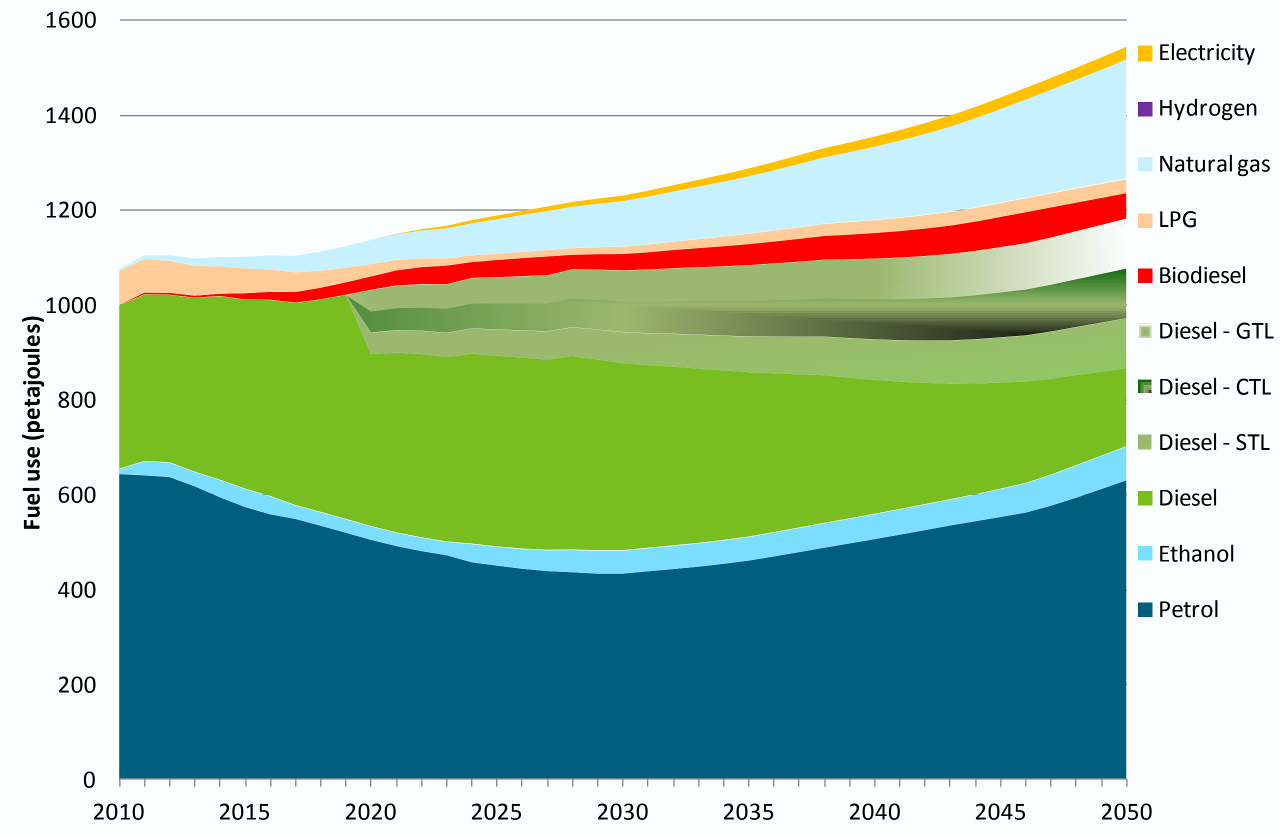

Figure 5-20: Projected road transport fuel consumption by fuel under the no carbon price scenario

Figure 5-21 shows the projected level of non-road transport consumption by fuel and mode (domestic navigation, rail and domestic aviation) for the no carbon price scenario. This scenario features the lowest uptake of non-crude oil based fuels, especially in domestic aviation.

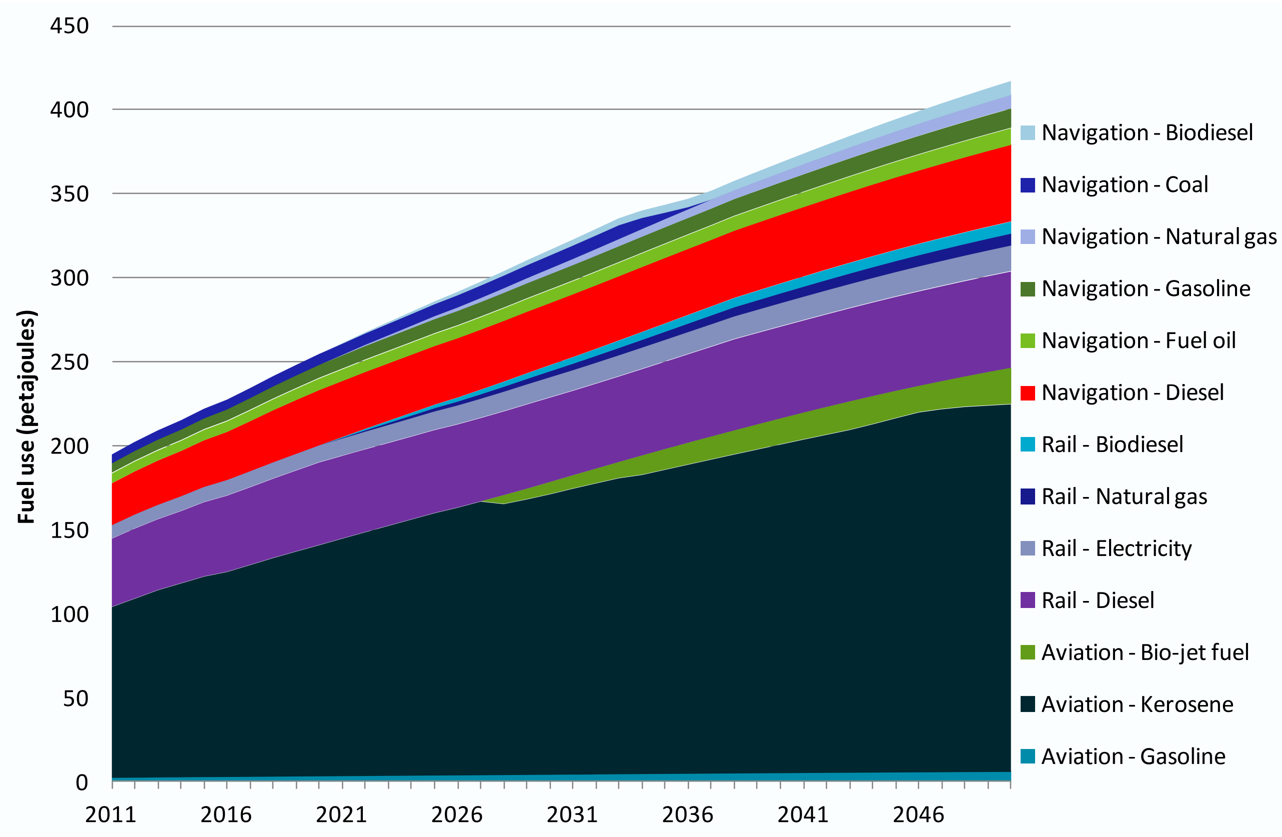

Figure 5-21: Non-road transport fuel consumption by fuel and mode under the no carbon price scenario

5.4.2 ROAD SECTOR ENGINE MIX

Figure 5-22 shows the engine type in road kilometres travelled for the no carbon price scenario. The impact of no carbon price is that the uptake of alternative drivetrain vehicles is mainly limited to hybrids with plug-in hybrid and fully electric vehicles unable to achieve significant market share.

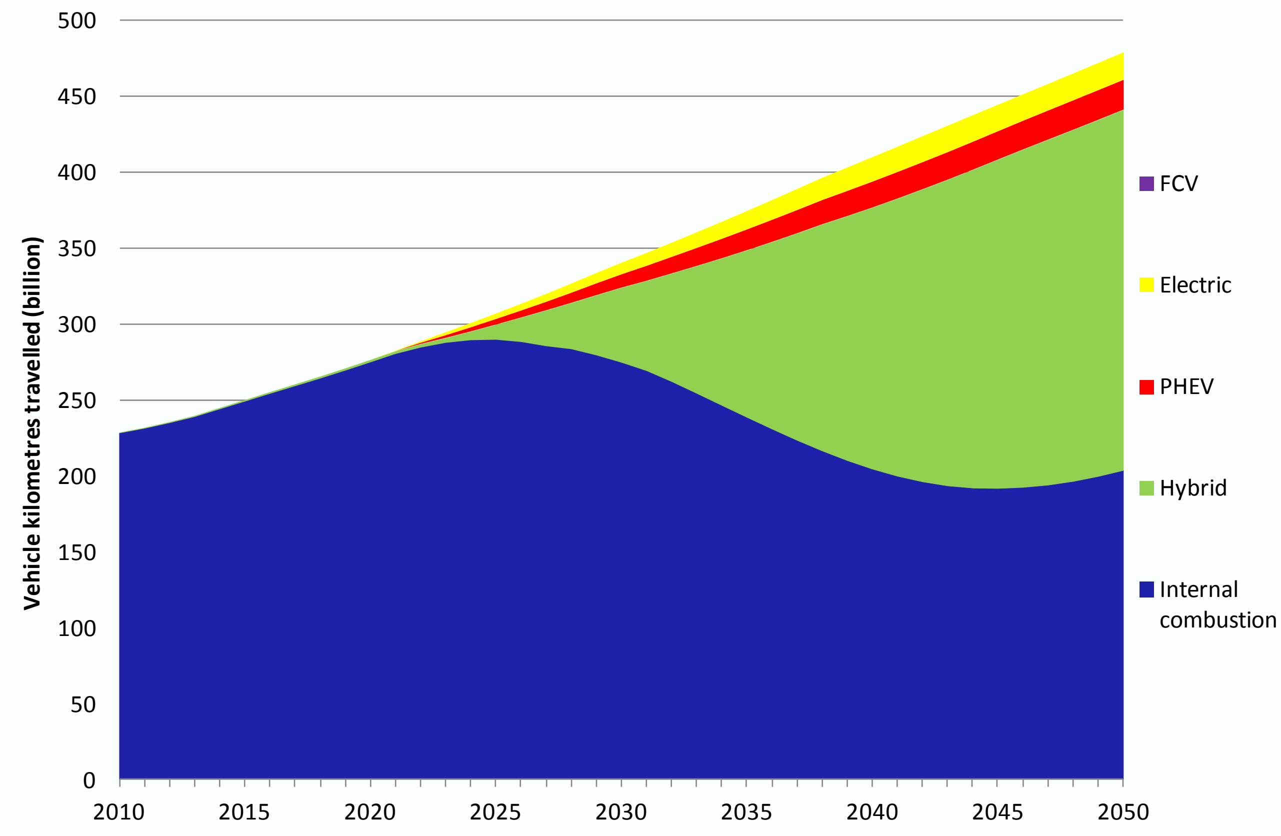

Figure 5-22: Engine type in road kilometres travelled, no carbon price scenario

5.4.3 GREENHOUSE GAS EMISSIONS

Figure 5-23 shows the greenhouse gas emissions by mode for the road transport sector under the no carbon price scenario. The lack of a carbon price signal in conjunction with higher activity levels compared to the central policy scenario means that road sector greenhouse gas emissions continue to rise from around 2015 onwards. As a result, the uptick in emissions from synthetic diesel use around 2025 is less noticeable in this case. By 2050, road sector greenhouse gas emissions are 12 Mt higher compared to the central policy scenario.

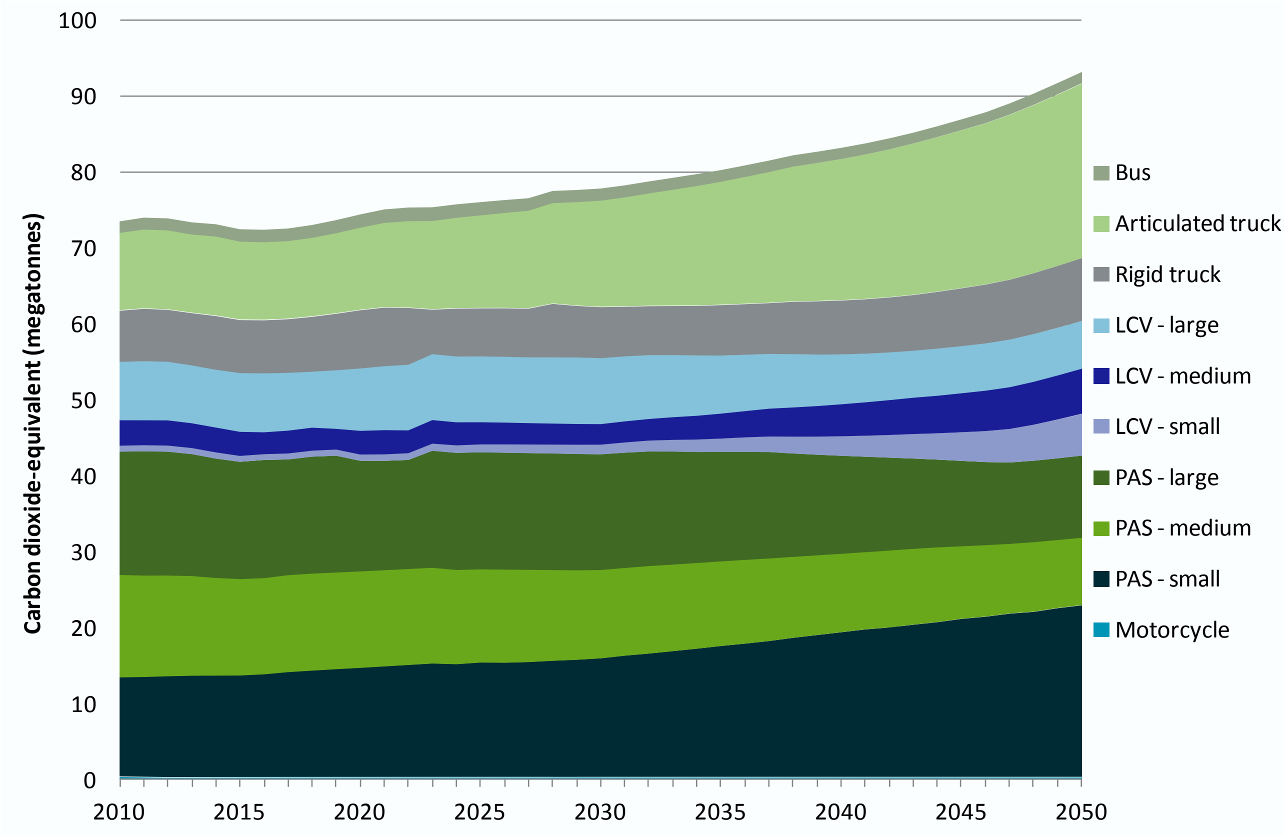

Figure 5-23: Road transport greenhouse gas emissions by mode under the no carbon price scenario

Similarly, the absence of a carbon price signal and more muted fuel and task efficiency improvements also mean that greenhouse gas emissions in the non-road transport sector nearly double over the projection period (Figure 5-24).

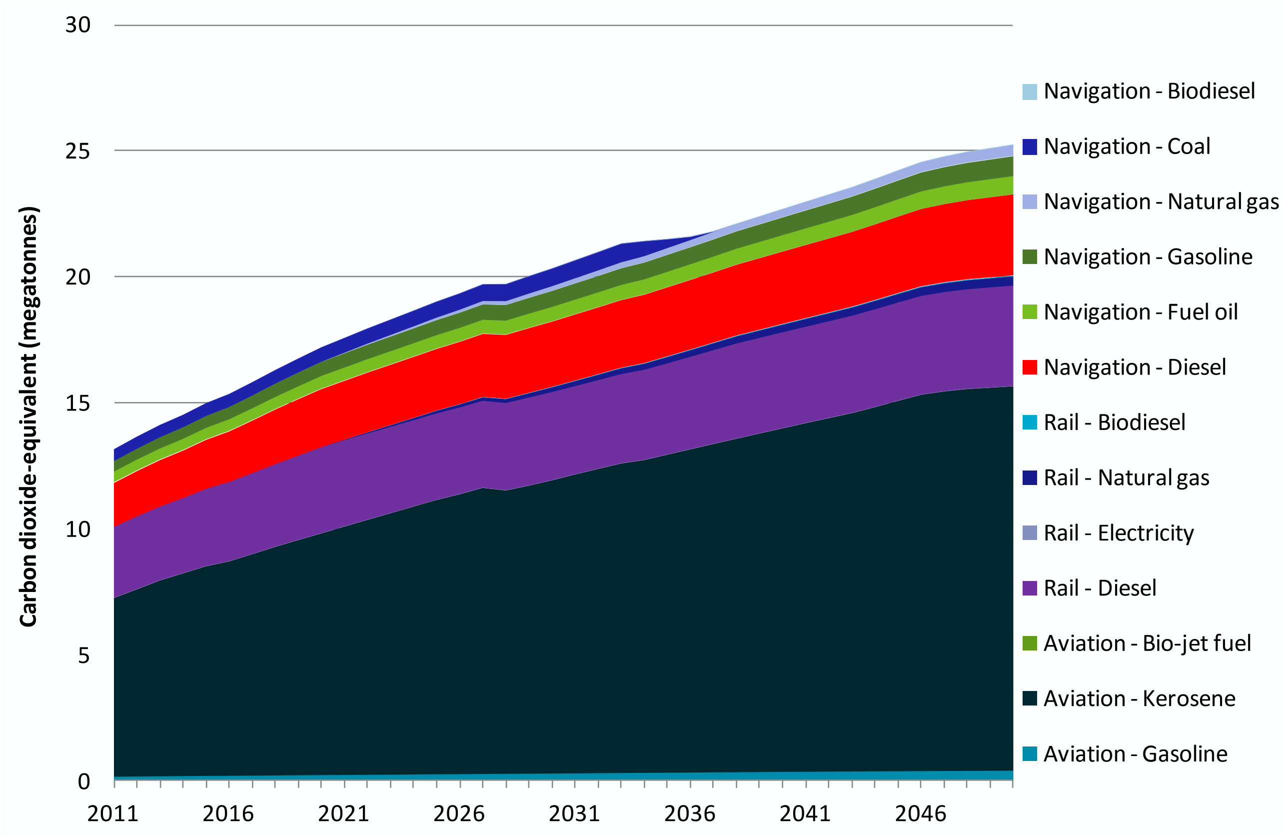

Figure 5-24: Non-road transport greenhouse gas emissions by mode under the no carbon price scenario

The net result is that transport sector greenhouse gas emissions are around 16 per cent higher in the no carbon price scenario relative to the central policy scenario (Figure 5-25) by 2050. At 2050, greenhouse gas emissions are around 17 Mt greater in the no carbon price scenario.

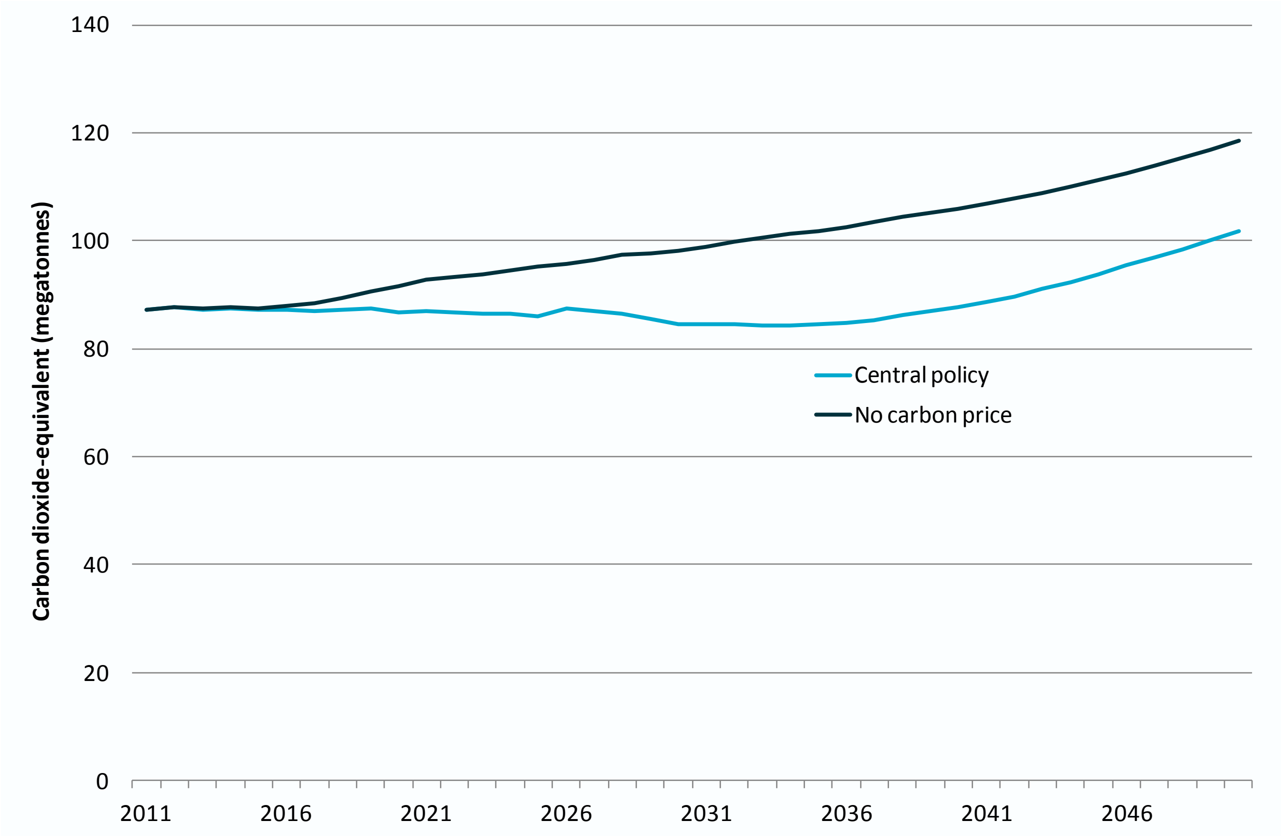

Figure 5-25: Transport sector greenhouse gas emissions under the no carbon price and central policy scenarios

6 Sensitivity cases

At the instruction of the Department, CSIRO was directed to test the sensitivity of the central policy scenario results to changes in some key assumptions in regard to policy measures and assumed oil price trajectories. This section outlines the main differences from the central policy scenario for each of the four sensitivity cases modelled:

- **Minimum efficiency standards for new cars** — Assumes that mandatory CO_2 emissions standards on all (imported and domestically produced) new light vehicles (passenger and light commercial vehicles) apply from 2015: 190g/km from 2015 onwards and 130g/km from 2020 onwards

- **No carbon price on heavy vehicles** — Assumes that the heavy road vehicle segment of the transport sector (rigid trucks, articulated vehicles and buses) are exempt from a carbon price for the entire projection period

- **High oil prices** — Assumes a higher oil price trajectory of $144/bbl in 2020, $220/bbl in 2035, and remaining constant at that level to 2050

- **Low oil prices** – Assumes a higher oil price trajectory of $125/bbl in 2020, $160/bbl in 2035, and remaining constant at that level to 2050.

The sensitivity cases are examined for the road transport sector only. This Section discusses the main points of difference in relation to the central policy scenario.

6.1 Minimum emission standards for new cars

This sensitivity case assumes that mandatory CO_2 emissions standards on all (imported and domestically produced) new light vehicles (passenger and light commercial vehicles) apply from 2015. The average emissions for new light vehicles sold in Australia in the years 2015-2020 must meet the following:

- An average CO_2 emissions target of 190g/km from 2015 onwards

- An average CO_2 emissions target of 130g/km from 2020 onwards.

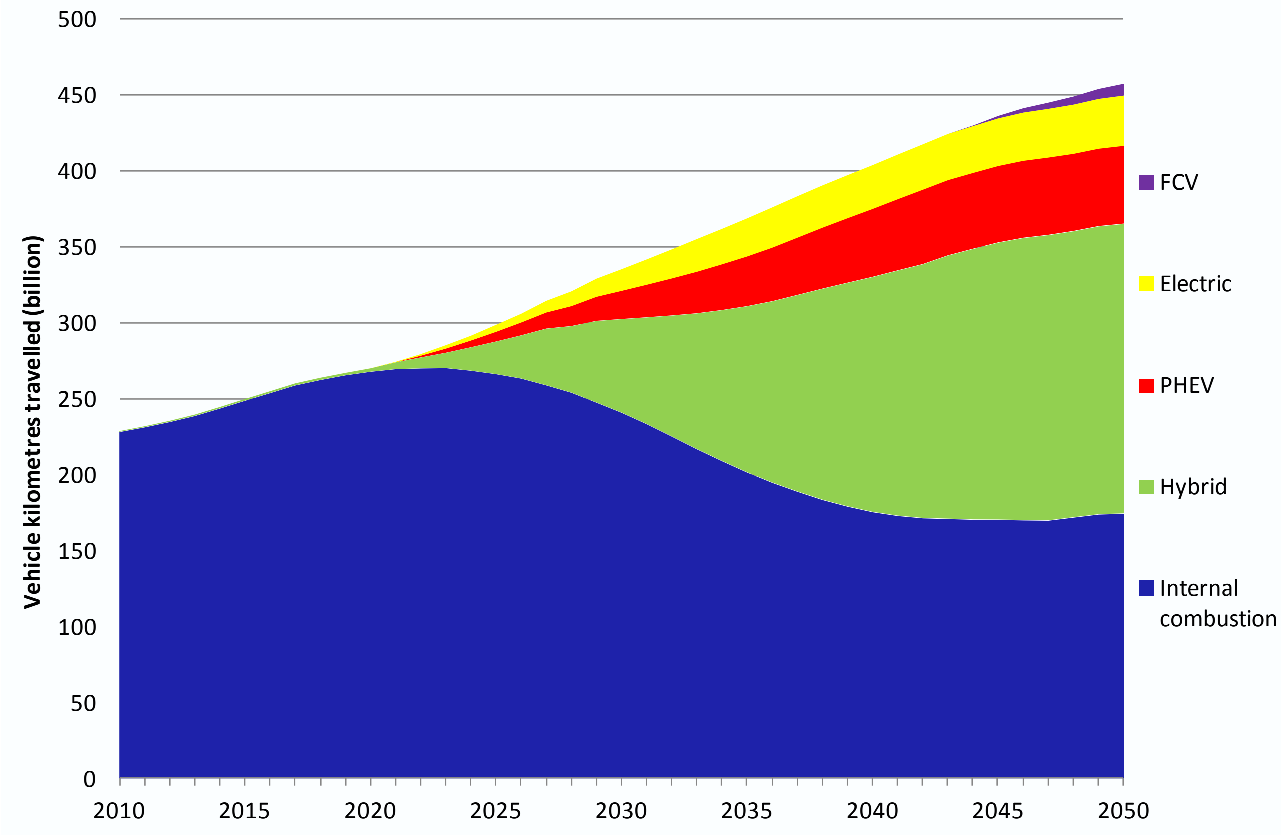

Figure 6-1: Engine type in road kilometres travelled, minimum efficiency sensitivity

Figure 6-1 shows the engine type in road kilometres travelled for the minimum efficiency sensitivity case. The impact of the new policy to 2015 appears muted suggesting that the average efficiency of new light vehicles can largely achieve the minimum standard. From 2015 to 2020, there is a slight increase in the deployment of hybrid vehicles with the policy having a greater effect after 2020 as shown in Figure 6-2. As this sensitivity has the central policy EV/PHEV availability assumptions, there is some uptake of fuel cell vehicles late in the projection period.

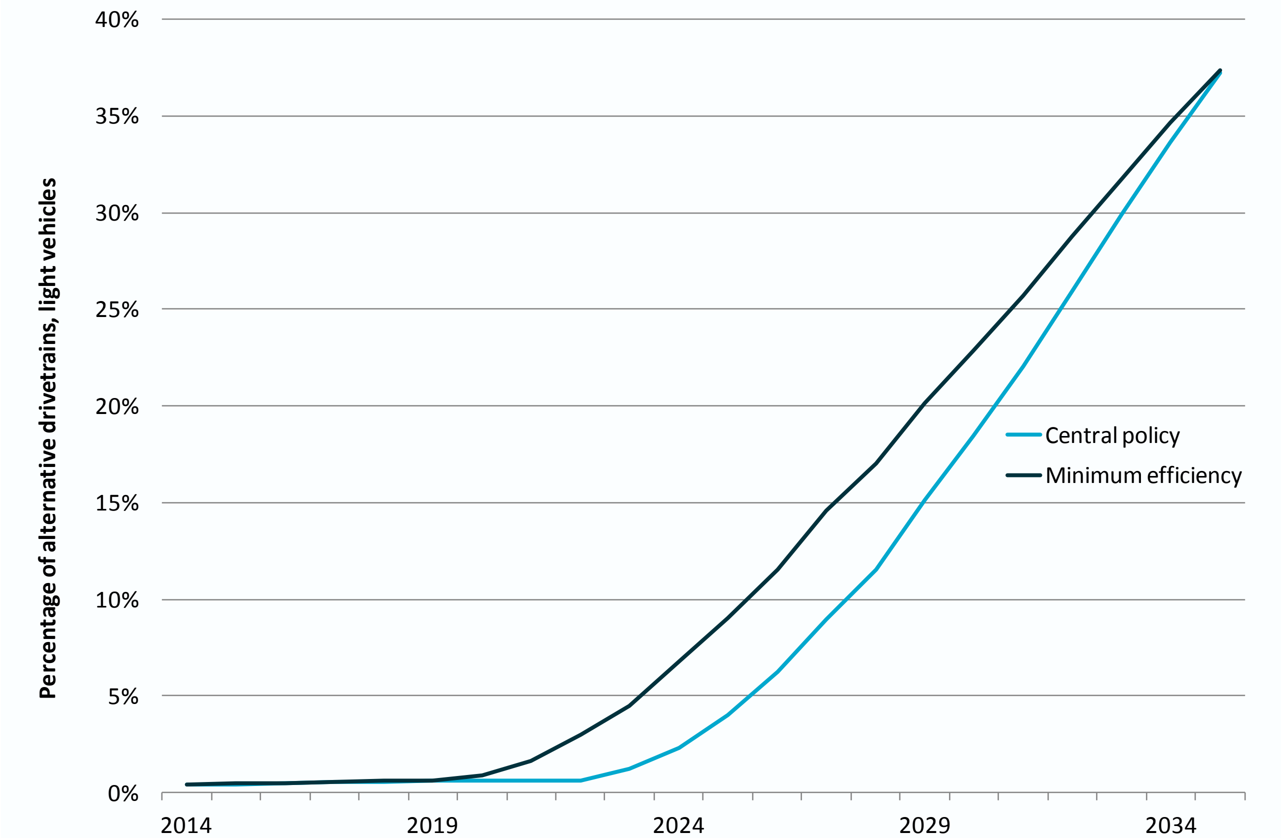

Figure 6-2: Comparison share of alternative drivetrains, central policy scenario and minimum efficiency sensitivity

It is not surprising that the impact is delayed until after the emission standards have been imposed. The standards only apply to new vehicle sales and so it will take some time for the more efficient vehicles to dominate the fleet.

The impact of the minimum emissions policy on road sector greenhouse gas emissions is evident in Figure 6-3. By 2015, road sector greenhouse gas emissions are around 1 Mt lower compared to the central policy scenario and around 3 Mt lower by 2020.

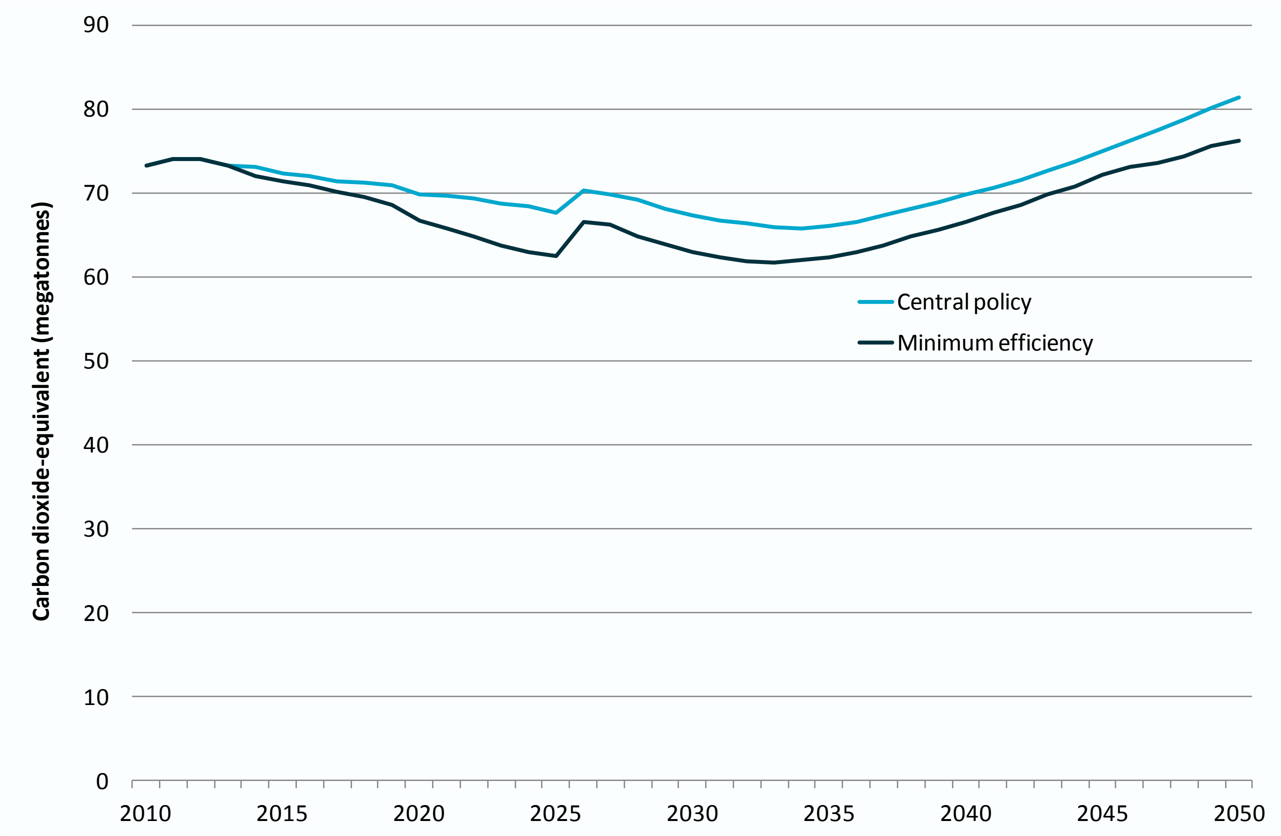

Figure 6-3: Road sector greenhouse gas emissions, central policy scenario and minimum efficiency sensitivity

6.2 No carbon price on heavy road vehicles from 2014

Under the central policy scenario, the on-road combustion of fuels by heavy vehicles is subject to a carbon price from 2014-15 onwards. This sensitivity case assumes that the heavy road vehicle segment of the transport sector (rigid trucks, articulated vehicles and buses) are exempt from a carbon price for the entire projection period. This sensitivity case essentially means that only the non-road transport sector is "covered" by the carbon pricing regime.

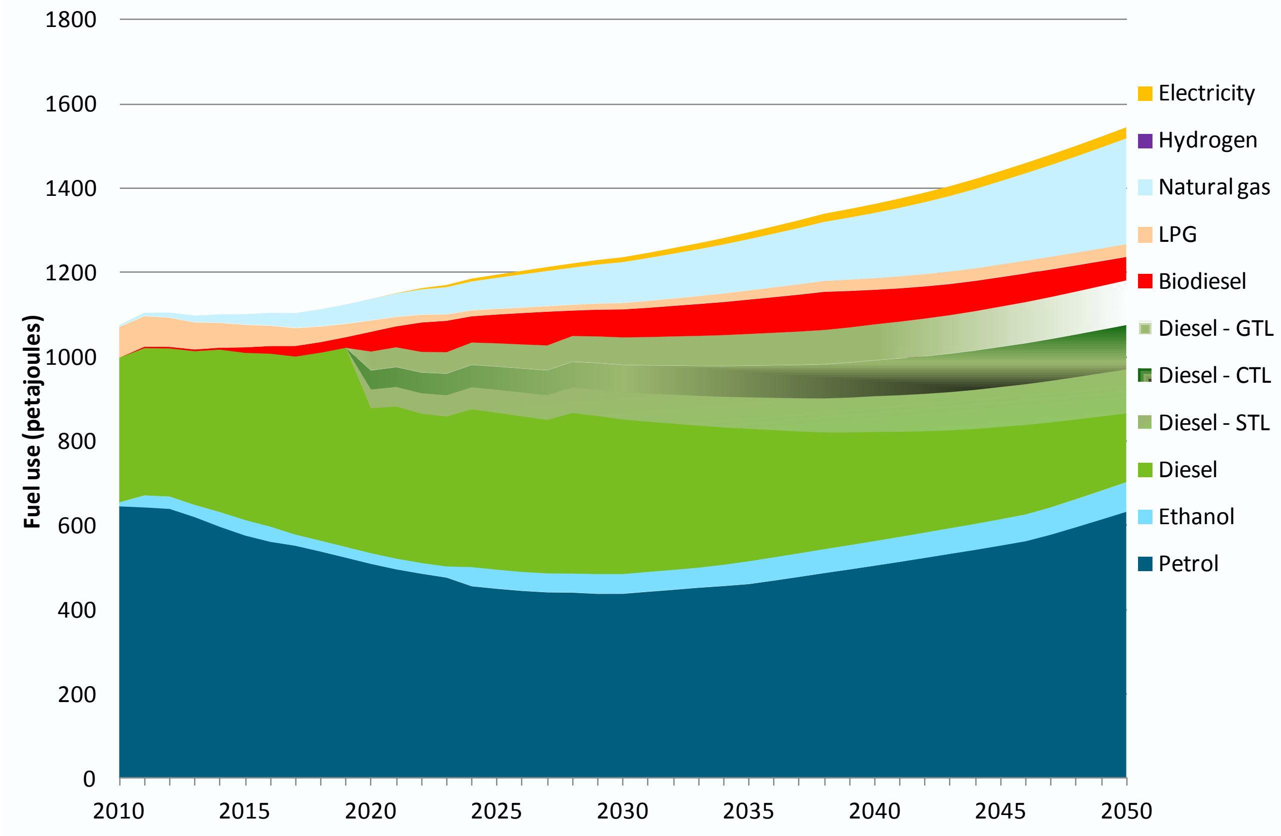

Figure 6-4: Projected road transport fuel consumption by fuel under the no carbon price on heavy vehicles sensitivity

Figure 6-4 shows projected road transport fuel consumption under the no carbon price on heavy vehicles sensitivity case. In general, the impact is that there is less incentive to take up low emission fuels (biodiesel, ethanol and electricity) when compared to the central policy scenario. As a point of interest, there is also less biofuel uptake in domestic aviation in this sensitivity compared to the central policy scenario. In 2030, biofuel equals around 9 per cent of domestic aviation fuel (22 per cent in the central policy scenario), by 2040 it is around 15 per cent (32 per cent in the central policy scenario), and by 2050 it is around 23 per cent (29 per cent in central policy scenario).

Figure 6-5 shows the impact on the percentage of low emission fuel use in road transport. Figure 6-6 also shows that the uptake of alternative drivetrain vehicles (hybrid, plug-in hybrid, fully electric and fuel cell vehicles) is more muted in this sensitivity case. The net result is that by 2050, around 7.5 per cent (110 PJ) more fuel is combusted by the road sector under the sensitivity case.

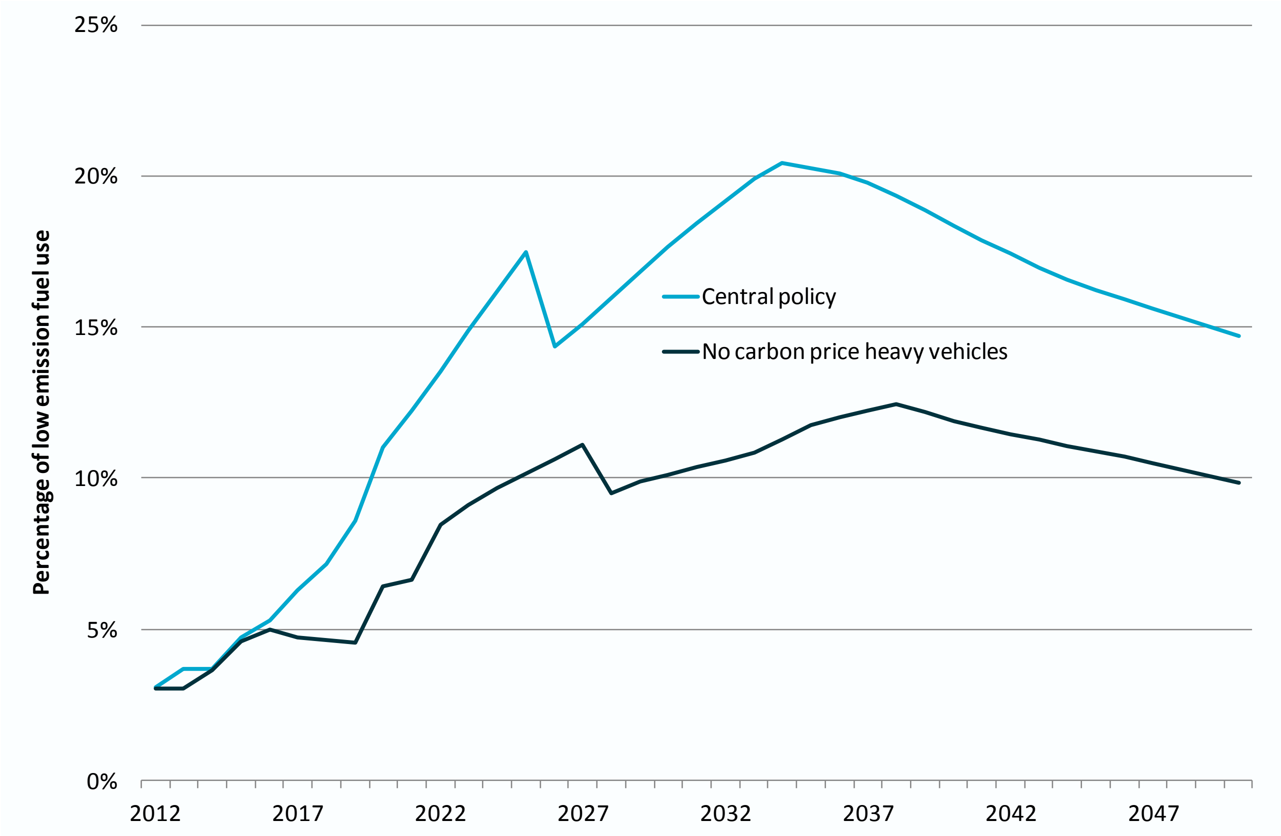

Figure 6-5: Comparison of low emission fuel use, central policy scenario and no carbon price on heavy vehicles sensitivity

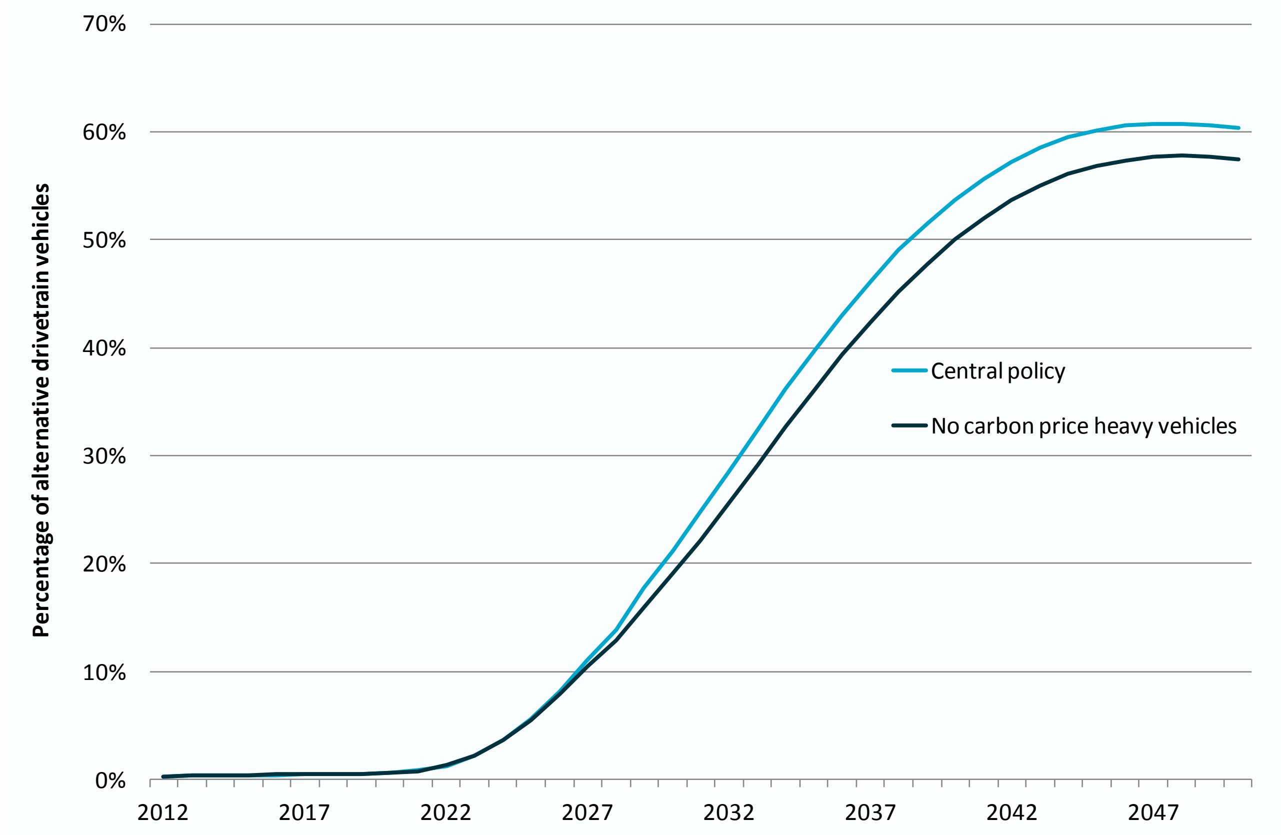

Figure 6-6: Comparison of alternative drivetrain vehicle uptake, central policy scenario and no carbon price on heavy vehicles sensitivity

The impact of more fuel use combined with less low emission fuel use is that road sector greenhouse gas emissions are around 14.5 per cent (12 Mt) higher compared to the central policy scenario by 2050 (Figure 6-7).

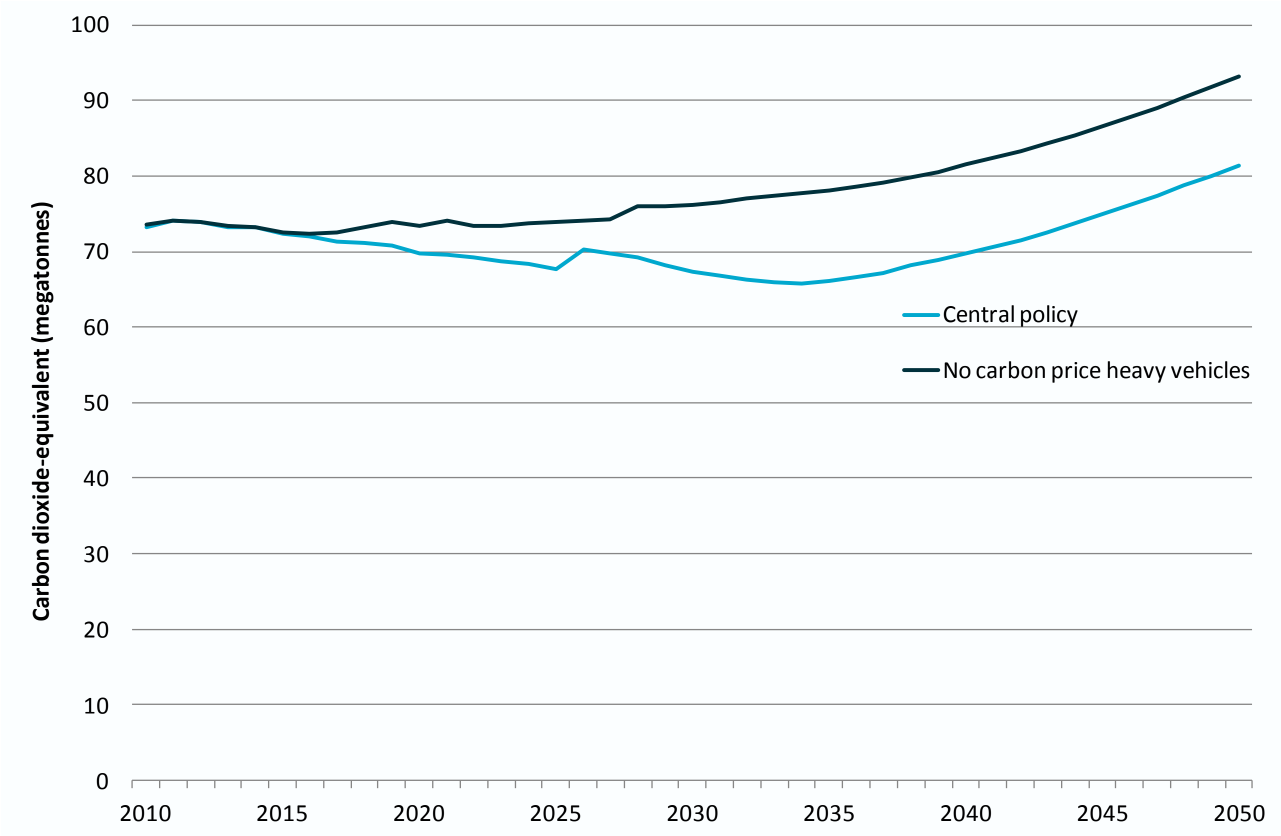

Figure 6-7: Road sector greenhouse gas emissions, central policy scenario and no carbon price on heavy vehicles sensitivity

6.3 High oil prices

This sensitivity case is to gauge the impact of high oil prices on the central policy scenario. Under the central policy scenario, oil prices are $134/bbl in 2020, $190/bbl in 2035, and are assumed to remain constant at that level to 2050. Under the high oil price sensitivity case, oil prices are $144/bbl in 2020, $220/bbl in 2035, and are assumed to remain constant at that level to 2050. All prices are in 2011/12 Australian dollar terms.

High oil prices leads to a small amount of demand response from around 2020 that reduces the demand for travel by around 1.3 per cent by 2050. However, similar the minimum efficiency standards sensitivity, high oil prices tend to encourage the uptake of alternative drivetrain vehicles.

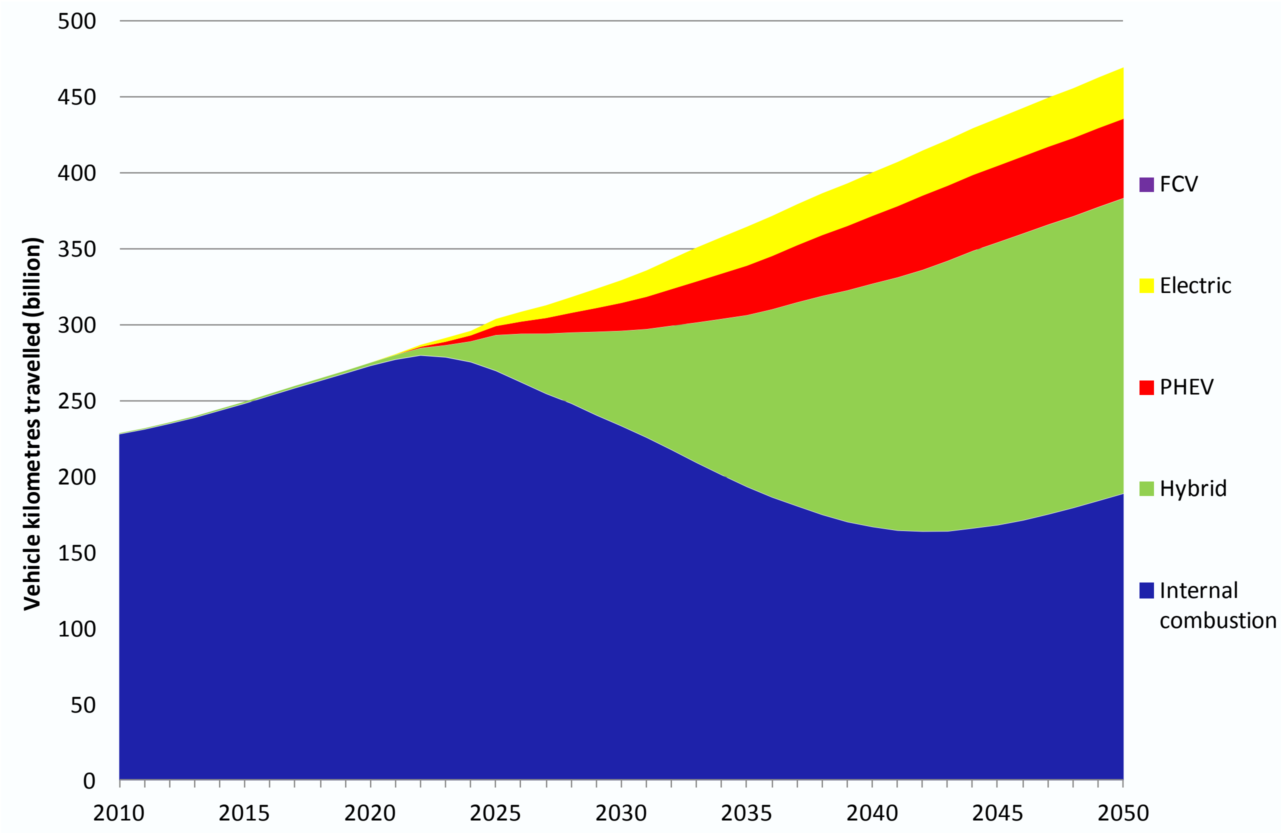

Figure 6-8: Engine type in road kilometres travelled, high oil prices sensitivity

Figure 6-8 shows that there is more incentive to take up hybrid and plug-in hybrid vehicles in this sensitivity case. Figure 6-9 shows a greater market share for alternative drivetrain vehicles with the differential narrowing by 2050, probably reflecting the assumption that vehicle costs are the same as the central policy scenario.

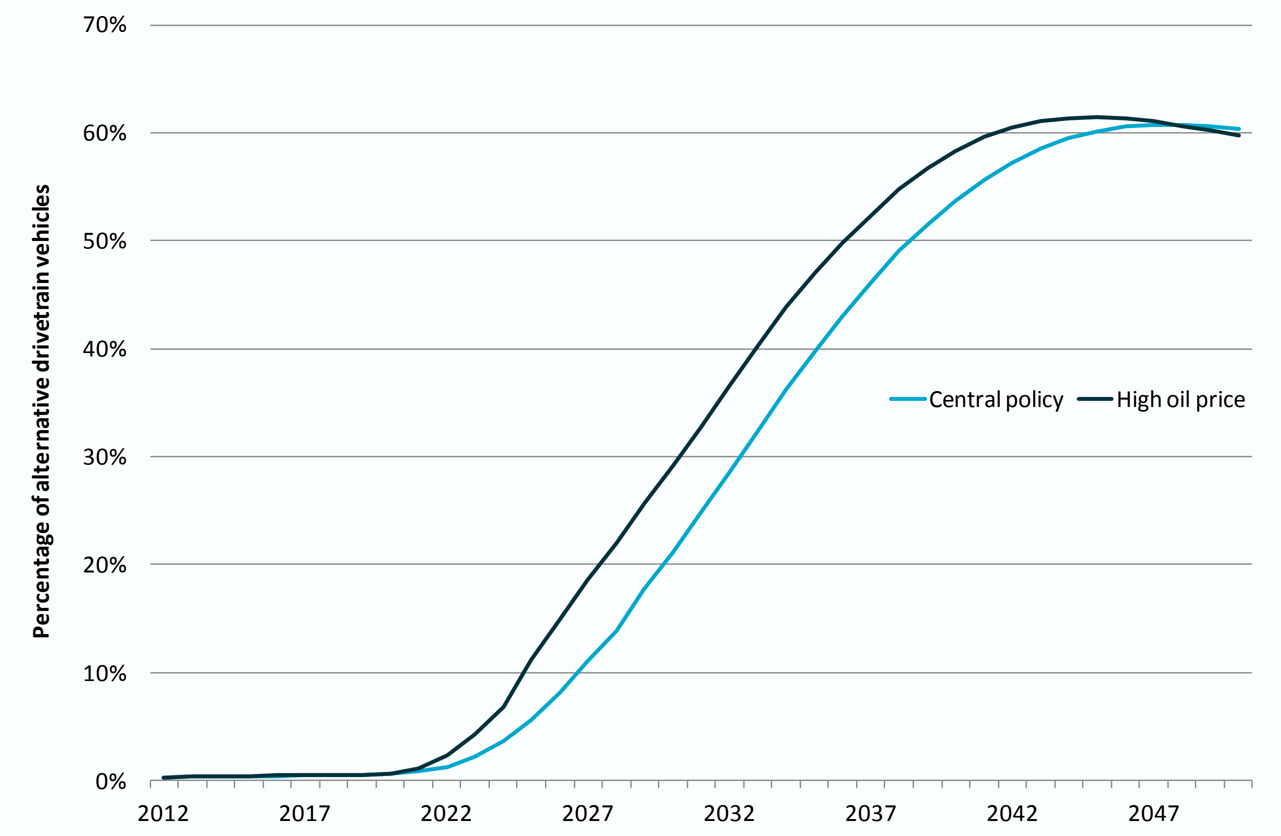

Figure 6-9: Comparison of alternative drivetrain vehicle uptake, central policy scenario and high oil prices sensitivity

Figure 6-10 shows that road sector greenhouse gas emissions are less than the central policy scenario.

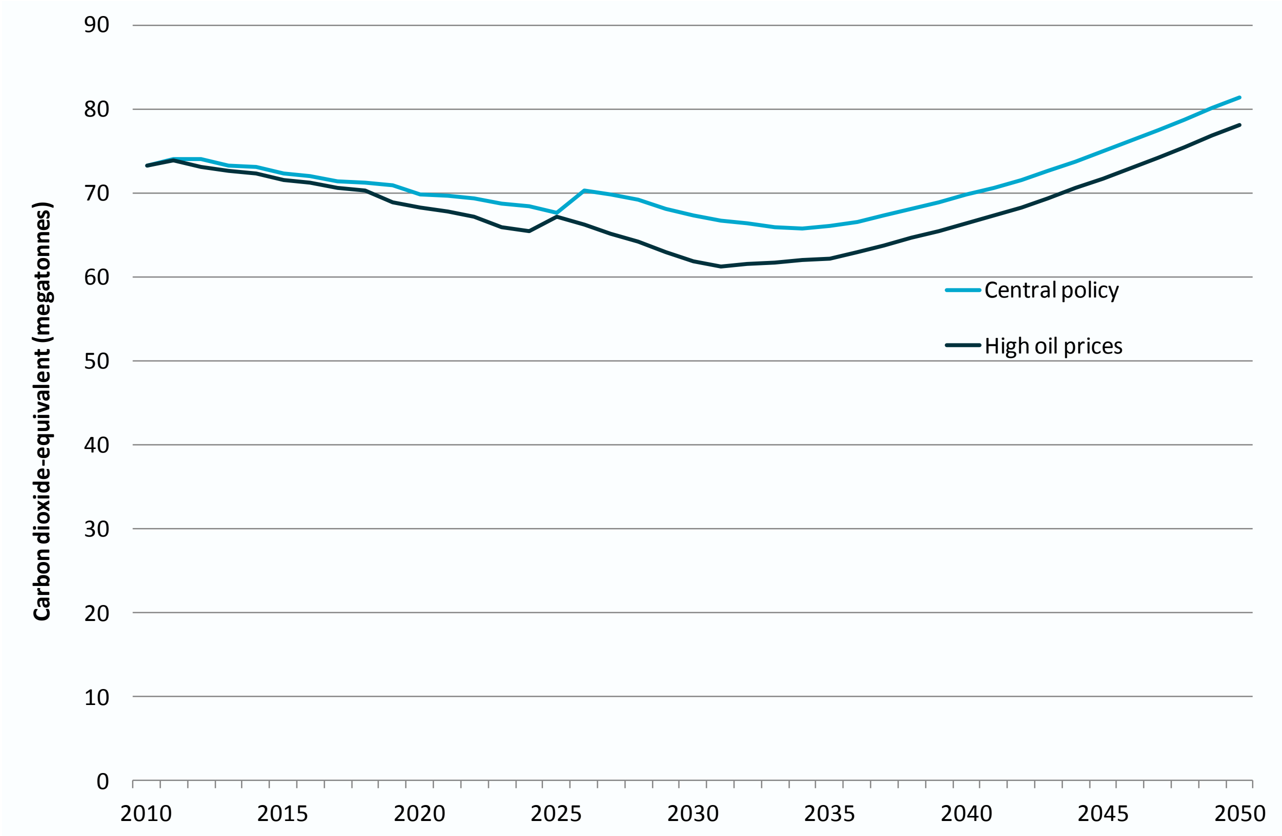

Figure 6-10: Road sector greenhouse gas emissions, central policy scenario and high oil prices sensitivity

6.4 Low oil prices

This sensitivity case is to gauge the impact of low oil prices on the central policy scenario. Under the central policy scenario, oil prices are $134/bbl in 2020, $190/bbl in 2035, and are assumed to remain constant at that level to 2050. Under the low oil price sensitivity case, oil prices are $125/bbl in 2020, $160/bbl in 2035, and are assumed to remain constant at that level to 2050. All prices are in 2011/12 Australian dollar terms.

This sensitivity is the obverse of the high oil prices sensitivity case with less incentive to take up hybrid and plug-in hybrid vehicles. . Figure 6-11 shows the projected vehicle kilometres travelled by engine type. Figure 6-12 shows a smaller market share for alternative drivetrain vehicles.

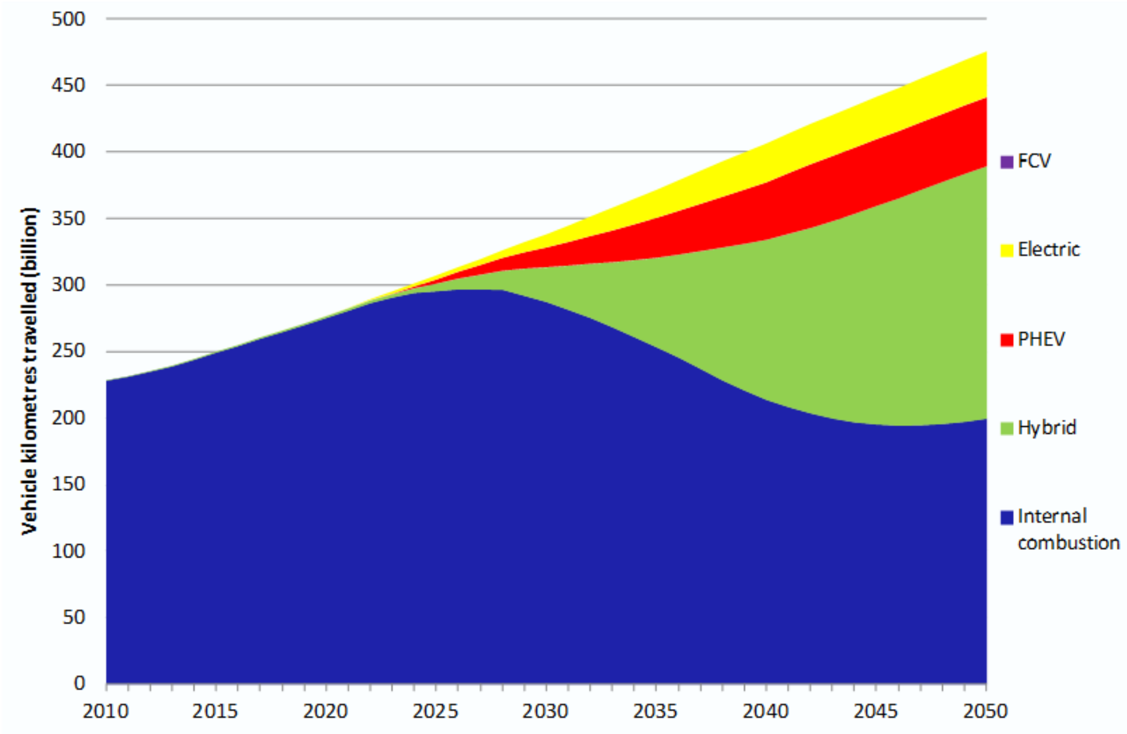

Figure 6-11: Engine type in road kilometres travelled, low oil prices sensitivity

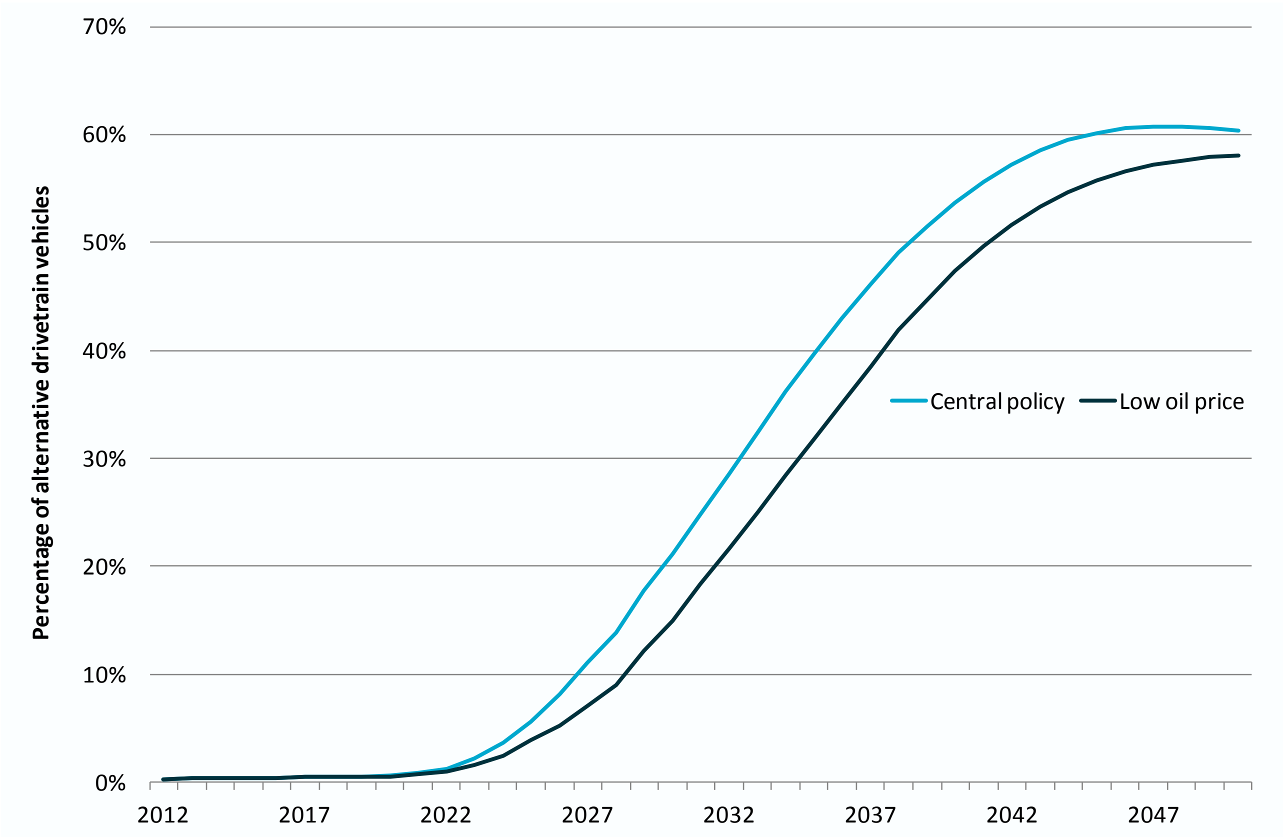

Figure 6-12: Comparison of alternative drivetrain vehicle uptake, central policy scenario and low oil prices sensitivity

The impact of more fuel use due to less uptake of alternative drivetrain vehicles is that road sector greenhouse gas emissions are around 14.5 per cent (12 Mt) higher compared to the central policy scenario by 2050, similar to the no carbon price on heavy road vehicles sensitivity case (Figure 6-13).

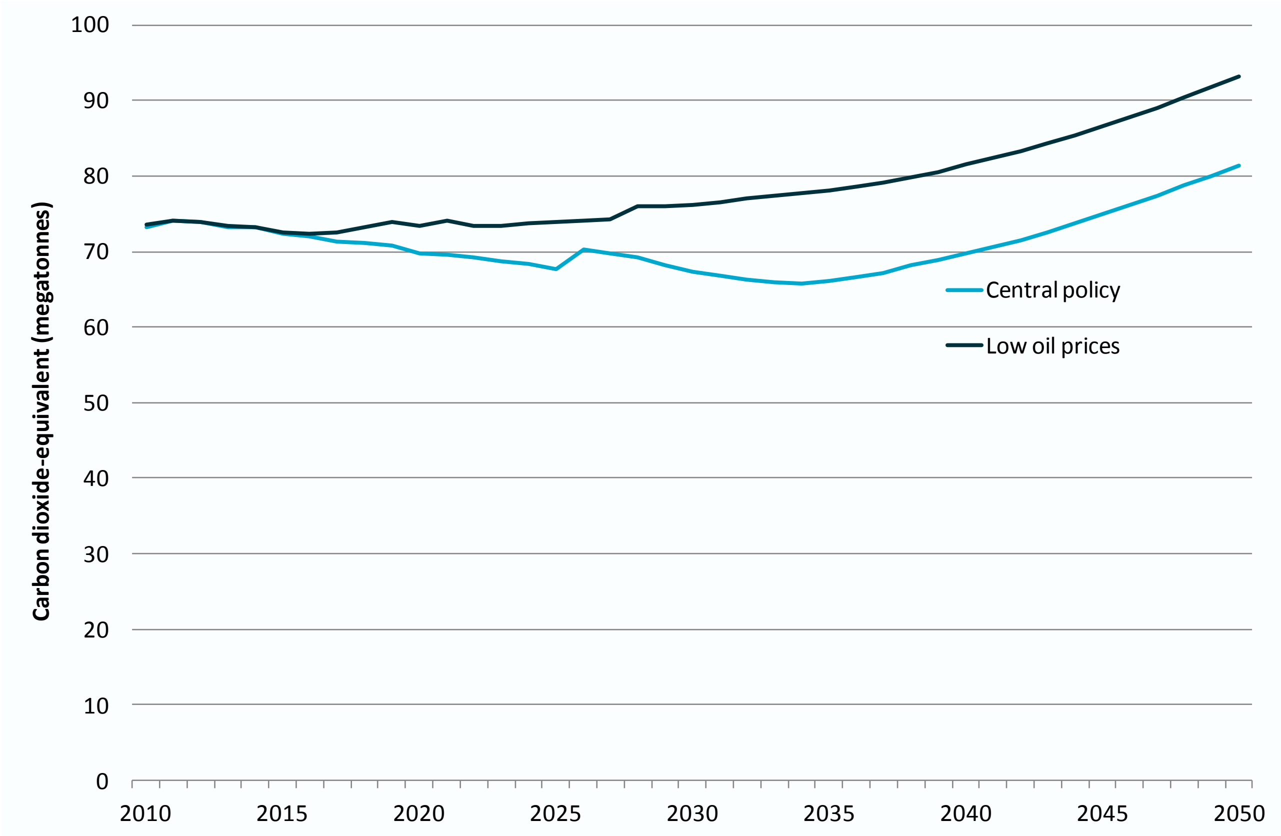

Figure 6-13: Road sector greenhouse gas emissions, central policy scenario and low oil prices sensitivity

6.5 Emission trading scheme 2015/16

Emission trading scheme 2015/16 (ETS 2015/16) is a sensitivity on the central policy scenario assuming that Australia adopts an emissions trading scheme in 2015/16 rather than in 2014/15 as under the central policy scenario.

The discussion of results will focus on the road transport sector as activity levels were unchanged between scenarios with the carbon price change not significant enough to deliver any technology impact or fuel switching in the non-road transport sector.

The impact of this two-year delay in transition to an ETS is largely indistinguishable from the central policy scenario. The comparison in road sector greenhouse gas emissions is shown in Figure 6-14.

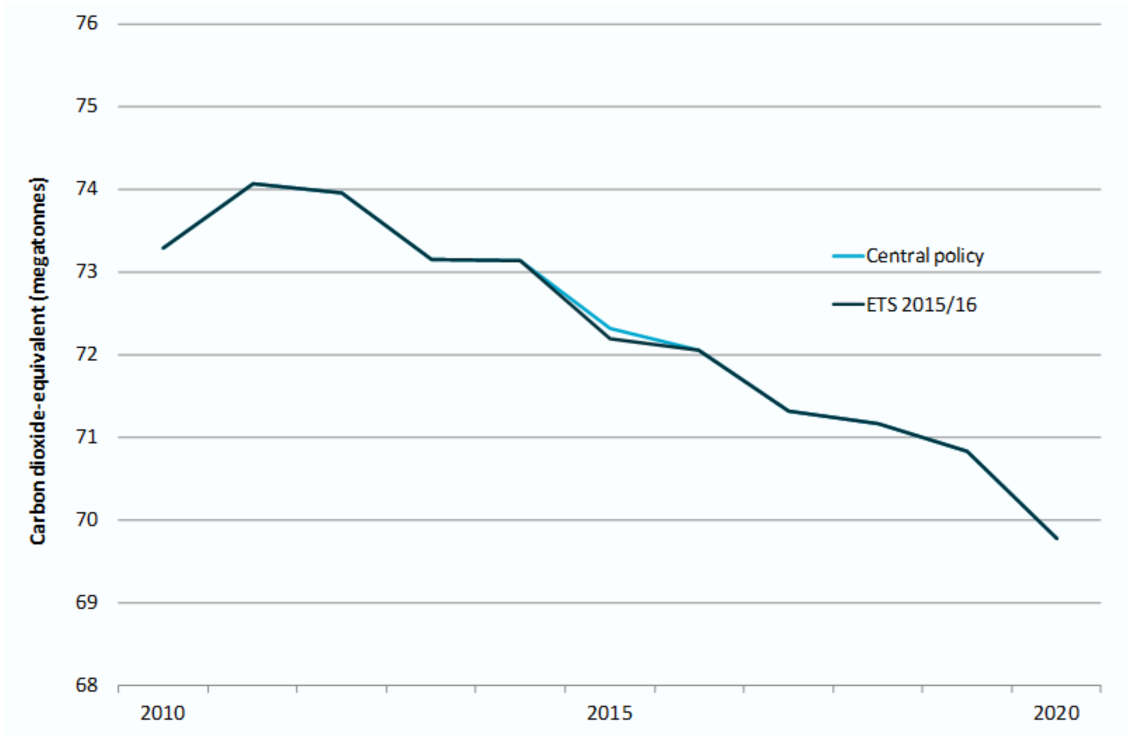

Figure 6-14: Road sector greenhouse gas emissions, central policy scenario and ETS2015/16 sensitivity

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Appendix A: Additional details of ESM road transport sector modelling and assumptions

The appendix provides additional detail about ESM modelling of the road transport sector.

A.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)

- Ten road transport modes: motorcycles, small, medium and large passenger cars; small, medium and large 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

- Fourteen road transport fuels: petrol; diesel; liquefied petroleum gas (LPG); natural gas (compressed (CNG) or liquefied (LNG)); petrol with 10 percent ethanol blend; diesel with 20 percent 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; shale 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 percent capture rate); brown coal pulverised fuel; brown coal IGCC; brown coal with CCS (90 percent capture rate); natural gas combined cycle; natural gas peaking plant; natural gas with CCS (90 percent 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; and

- 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.

A.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, and
- 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.

A.3 Road vehicle type configuration

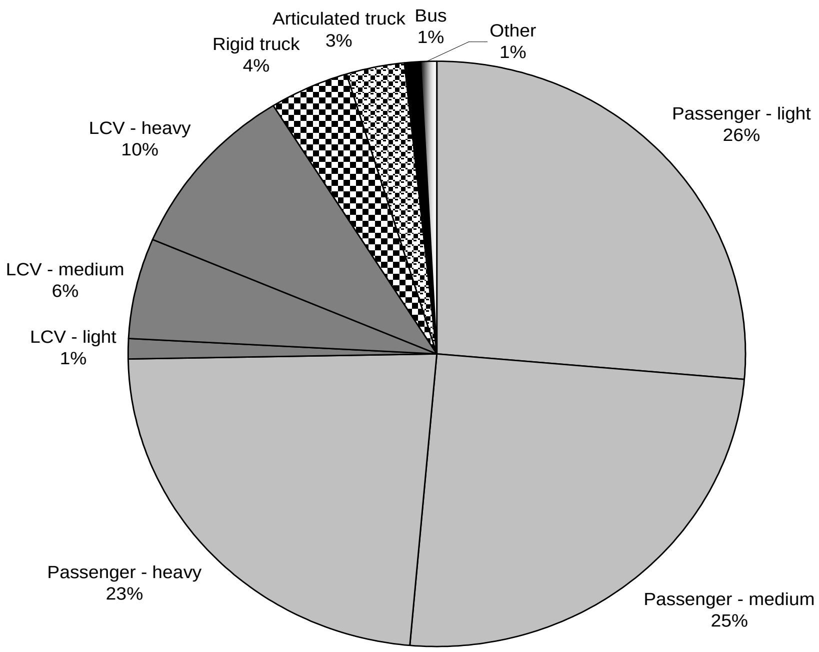
An important consideration in the transport model is how to represent the vehicle type combinations that are of interest. In theory, one could construct a model of the Australian road transport sector which included every make of existing vehicle type and possible future types. In practice, modellers 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 ABS (2007) and the vehicle weight categories based on data therein.



Source: ABS (2007).

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

A.4 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 percent ethanol (E10)
- Ethanol blend with up to 85 percent ethanol and 15 percent petrol (E85)[10]
- Diesel (DSL)
- Diesel with 20 percent biodiesel blend (B20)
- 100 percent biodiesel (B100)
- Liquefied petroleum gas (LPG)

[10] 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.

- 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
- Shale to liquids (STL) diesel with upstream CO_2 capture and storage, and
- Electricity (ELE).

This is obviously not a complete list of possible fuels but covers those that are generally of greatest interest in the Australian marketplace at the time of the study.

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

Table A-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
B100	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
STL	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.

A.5 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 available in all vehicle categories Hybrids (HYB) are not allowed in the light passenger/LCV vehicle category since it would be unlikely that the fuel savings achieved through hybridisation would be cost effective given the high existing fuel efficiency of this vehicle category. Medium and heavy/large passenger and light/small commercial vehicle categories are also 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.

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

Table A-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	x	x	x	x	
FCV	x	x	x	x	x	x	x	x	

A.6 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).

A.6.1 VEHICLE COSTS

Table A-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 (greater than 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 NRMA (2011).

Table A-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 (2009); Electrification Coalition (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 A-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 A-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 (HYBs), 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 A.7.

A.7 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 A-5. The assumption regarding hybrid vehicles (HYBs) is that over two decades mild hybridisation of vehicles will become standard and will not involve significant additional cost.

Similar to HYBs, 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 A-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 (2011); IEA (2009); Electrification Coalition (2009); ANL (2009).

A.8 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.

A.8.1 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 $US60-110/bbl and $US40-110/bbl, respectively. Shale to oil (STL) production costs are assumed to lie within a similar range. The cost of CO_2 capture and storage for CTL and STL diesel is assumed to be $20/t$CO_2$e. STL, CTL diesel and GTL diesel are assumed to be available only after 2020.

A.8.2 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 A-2 and Figure A-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.

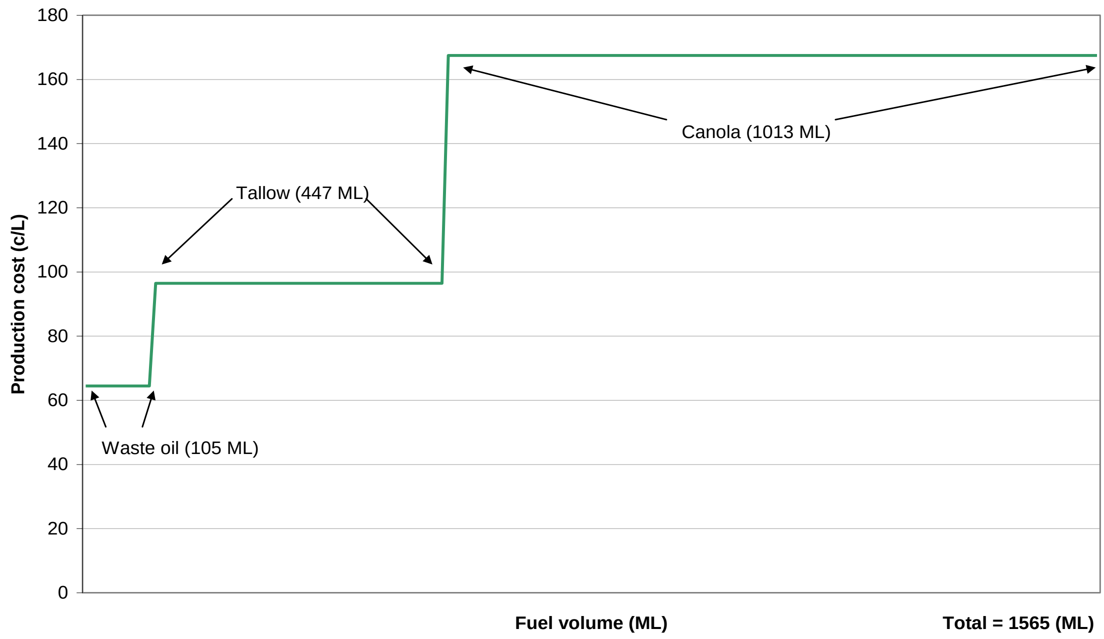


Figure A-2: First generation biodiesel cost-quantity curve

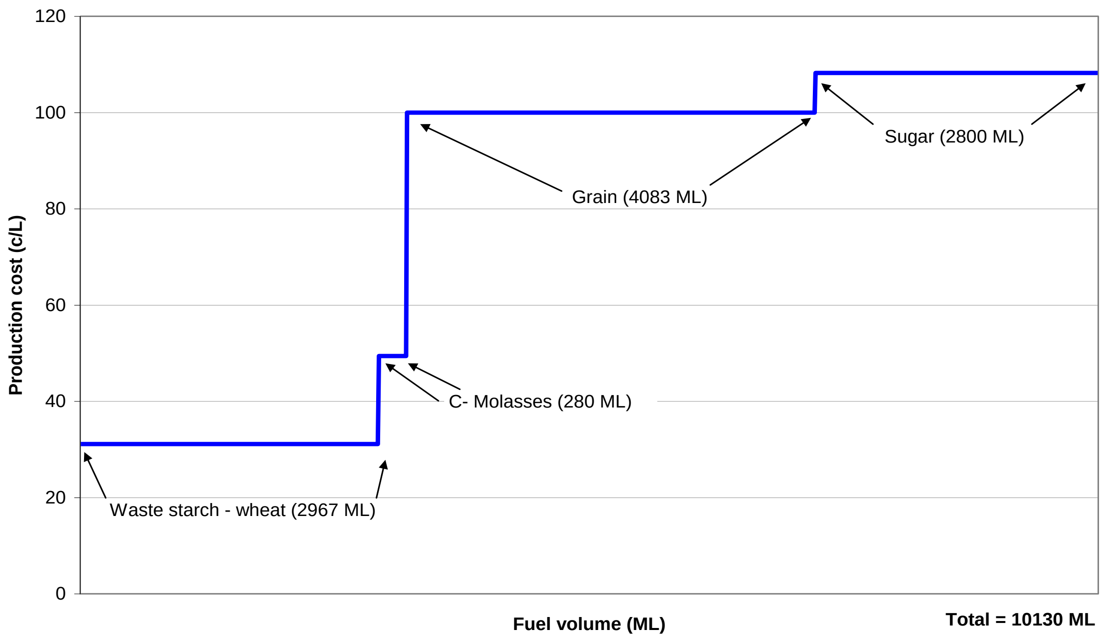


Figure A-3: First generation ethanol cost-quantity curve

A.8.3 ADVANCED GENERATION ROAD BIOFUELS

Figure A-4 and Figure A-5 shows the cost curve as a function of biomass availability and component costs for the production of advanced generation road biofuels respectively. The charts use advanced generation biofuel supply data based on detailed feedstock assessment (Farine et al., 2011).

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

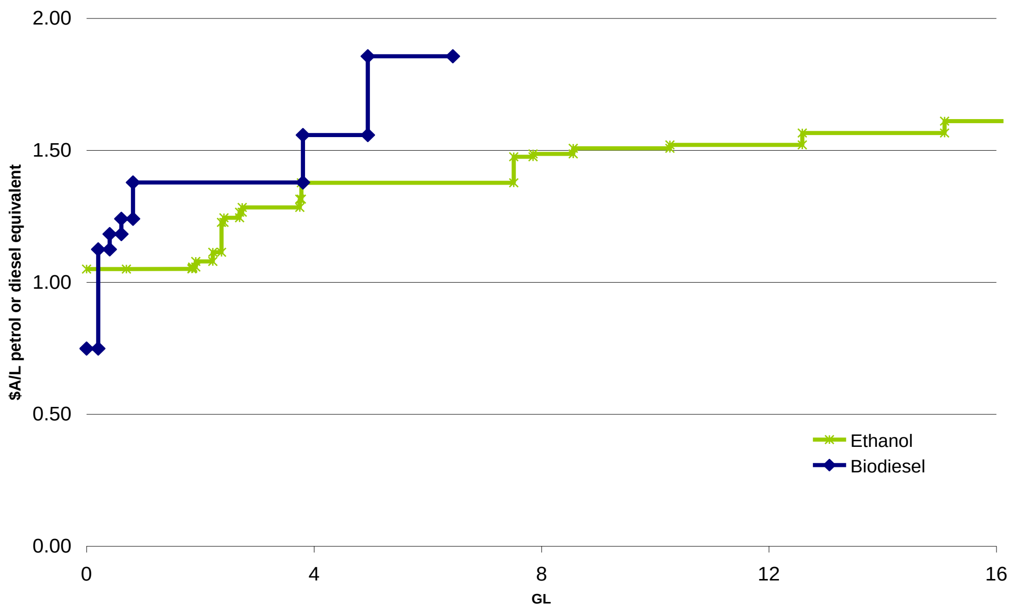


Figure A-4: Cost curve for advanced generation road biofuels

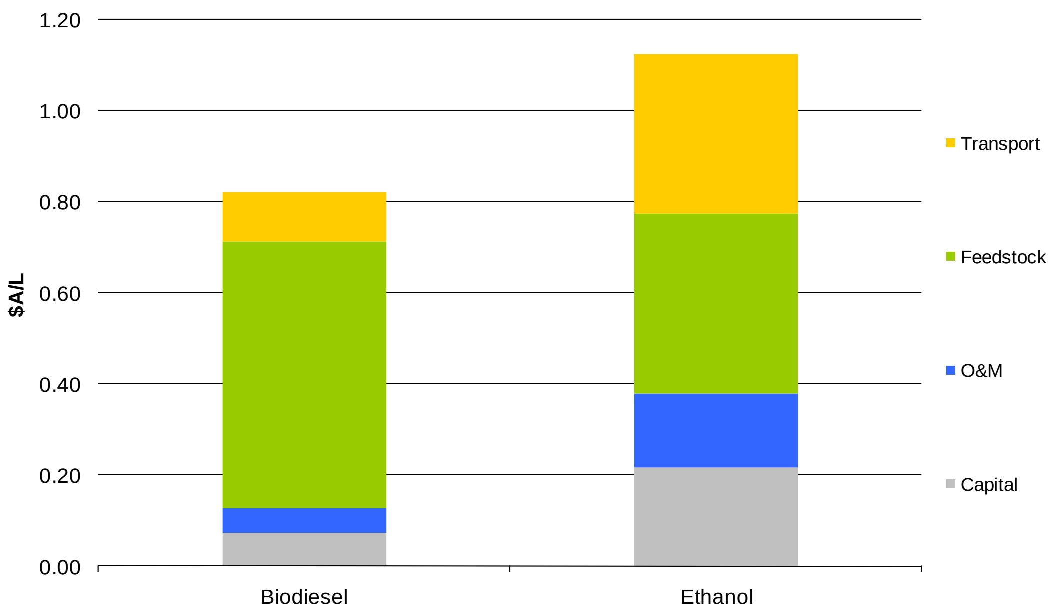


Figure A-5: Component costs for advanced generation production of ethanol and biodiesel

A.9 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 A-6. In some cases there is considerable uncertainty since energy content can vary due to different feedstocks, particularly for biofuels.

Table A-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	43.0	0.84	33.6
STL diesel	43.0	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 A-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 A-7: Combustion process according to fuel

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

A.9.1 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 percent of average adult annual income).

It is assumed that vehicles equipped with SI engines will improve in efficiency by 25 percent and CI engines by 14 percent from 2006 to 2050, independently of changes related to fuel type and hybrid drive-train. 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 valve-trains
- Increase in compression ratio towards optimum values, enabled by the use of direct injection and advanced valve-trains
- 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 reference 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 A-9 presents assumptions about road vehicle fuel intensity by fuel type for conventional ICE vehicles.

Combined with non-engine efficiency improvements, fuel intensities for ICEs are assumed to decline up to 37 percent 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 percent improvement in fuel efficiency starting in 2006 increasing to a 30 percent improvement by 2050 for all road categories except for articulated trucks. Articulated trucks improve to only 10 percent 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 drive-train it has the ICE-only efficiency for that year. When using the electric drive-train it has the following efficiencies:

- Light passenger: not applicable
- Medium passenger: 0.18 kWh/km
- Heavy passenger: 0.27 kWh/km
- Rigid truck: 0.85 kWh/km
- Bus: 0.8kWh/km.

These electric drive-train 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 drive-train in total annual kilometres is assumed to be 50 percent initially in 2006, increasing to 80 percent by 2035 as battery technology improves and allows for greater use of the electric drive-train. For the remainder of kilometres the ICE drive-train is in use. As such, a weighted average of the efficiency of these drive-trains 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 drive-train 100 percent of the time at 0.16 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 drive-train efficiency are used up to provide better amenity.

Note, at an off-peak 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 1.4c/km. This is 12 percent of the 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 A-8: 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 /STL 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).

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