Outlook for the New Zealand Energy Economy to 2050 including the Role of Hydrogen
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1 Executive summary

A comparison of UniSyD and the Ministry of Economic Development (MED) model outcomes was undertaken based on the MED Energy Outlook 2011 [1]. All comparisons are given in real prices. In the comparison scenarios oil prices reach US$130 per bbl in 2030 with an emissions price of $25/t-CO$_{2eq}$ from 2013. In addition two units at the Huntly coal fired power station are switched to dry year reserve in 2012 and 2015 respectively. No further coal stations are built.

The main findings of the comparison are:

i. MED predicts increases in geothermal and wind generation by 2040 of 38 PJ and 20 PJ respectively. UniSyD predicts increases in geothermal and wind generation by 2040 of 20 PJ and 40 PJ respectively.

ii. Both UniSyD and MED predict an average wholesale price of electricity to 2040 of about 10 c/kWh.

iii. UniSyD transport energy projections in 2050 are 30% lower than MED projections. UniSyD predicts the fuel economy of ICEVs will reduce faster than that predicted by MED.

iv. MED predicts greater emissions from electricity generation from coal to 2040. Coal emissions from MED and UniSyD are 19.6 Mt-CO$_{2eq}$ and 12.4 Mt-CO$_{2eq}$ respectively.

Selected sectors of the energy economy of New Zealand are modelled in eight different sensitivity scenarios using UniSyD. The sectors include road transport as well as generation and production options for electricity, biofuels and hydrogen. In the sensitivity scenarios maximum oil prices to 2050 range from US$97/bbl to US$170/bbl and carbon prices from $25/t-CO$_{2eq}$ to $182/t-CO$_{2eq}$. Of the eight scenarios examined the GreenGrowth and GreenGrowthMax are closely aligned with the future energy policies of New Zealand and reflect increasing concern in the use and supply security of fossil fuels. In these scenarios the oil price reaches US$130 per bbl in 2030. The emissions tax is constant at $50/t-CO$_{2eq}$. In the GreenGrowthMax scenario fiscally neutral instruments are employed to encourage the uptake of alternative fuelled vehicles.

The opportunity costs or savings associated with hydrogen fuel cell vehicles (FCV) are examined in relation to the GrowthGreen and GrowthGreenMax scenarios. The analysis is restricted to capital cost, fuel cost, and carbon charges. The adoption of FCV technology returns a net opportunity saving of between $1.1 billion and $4.3 billion by 2050. This benefit consists of annual savings in fuel of $130 - $210 million and savings in carbon taxes of $30 - $45 million. These savings are reduced by increased annual vehicle capital investment of up to $130 million. The opportunity savings rise to a maximum $8.4 billion for an oil price of US$170/bbl from 2030.

The average annual saving in greenhouse gas (GHG) emissions is 600 - 900 kt-CO$_{2eq}$. Annual petrol and diesel savings are 220 – 480 million liters.

Modeling shows the light road transport fleet will continue to be dominated by internal combustion engine vehicles (ICEV) and hybrid electric vehicles (HEV) to 2050 with these modes comprising 84% and 75% respectively under the MEDGreen and GrowthGreen scenarios. Under fiscally neutral vehicle incentive policies modelled in the GrowthGreenMax scenario the proportion of ICEVs and HEVs in the light fleet is reduced to 49%. Under the MEDGreen, GrowthGreen and GrowthGreenMax scenarios FCV fleet penetration is 0%, 9% and 22% respectively. For these three scenarios PHEV penetration ranges from 7% - 17% while biofuelled internal combustion engine vehicles (BICEV) constitute 5% - 8%. Electric
vehicles (EV) account for 1% except in the GrowthGreenMax scenario where market share rises to 7%.

The heavy road transport fleet will continue to be dominated by ICEVs and HEVs to 2050 with these modes comprising 65% and 58% respectively under the MEDGreen and GrowthGreen scenarios. BICEVs comprise 28% of the fleet in 2050 for these scenarios. Under fiscally neutral vehicle incentive policies modelled in the GrowthGreenMax scenario the proportion of ICEVs and HEVs in the heavy fleet is 66%. However the proportion of BICEVs reduces to 16%. Under the MEDGreen, GrowthGreen and GrowthGreenMax scenarios FCV fleet penetration is 0%, 8% and 14% respectively. For these three scenarios PHEV penetration ranges from 5%-7% while BICEVs constitute 16%-28%. Most heavy plug-in hybrid electric vehicles (PHEV) are likely to be made up of vehicles at the lighter end of the heavy classification and operated from a central depot.

The average reduction in GHG emissions for the period 2010-2050 across all eight scenarios is 21% with a range of -17% for MEDFossil to +35% for IEA450 and MEDGrowthFossil.

Renewable electricity generation across all scenarios increases by an average of 3% from 79% to 82% between 2020 and 2050. The balance of generation is predominantly natural gas.

New Zealand has a large resource base of renewable energy. Providing sufficient peak load gas fired generation can be maintained electricity prices are predicted to remain at about 10c/kWh (2008 dollars) to 2050.
2 Objective

This report is written in fulfilment of Objectives M2.5 and M2.6 of contract CO8X0803: “Hydrogen and Clean Energy”.

The objectives are:

(a) Objective M2.5
Carry out a detailed examination of the economic impacts of high oil prices on the need for a hydrogen energy infrastructure; identify cost trends and environmental benefits for the introduction of battery, biofuel and hydrogen fuel cell vehicle mixes under long term high oil scenarios; and firm up on the cost benefits of early uptake of hydrogen as an energy carrier under a scenario of rising oil prices.

Achievement Measure End date 30 Sept 2010.
Subject to IP restrictions, a public report of system dynamics modelling of the NZ energy system showing the opportunity costs of various uptake rates of hydrogen energy and fuel cells for transport in comparison with the other identified options.

(b) Objective M2.6 (as revised by the Governance Panel 2010)
Model the potential impact and interaction of the expanded range of possible end use transport technologies. This will result in model outputs associated with projected demand for the fuel options (eg, hydrogen and liquid synfuels).

Achievement Measure End Date 30 Sept 2012
A report to the Governance Panel of system dynamics modeling of the NZ energy system identifying any economic and GHG benefits from encouraging early uptake of hydrogen or of other new energy technologies.
3 Introduction

The objectives are examined in relation to eight scenarios as shown in Table 1. The first four scenarios are based on MED [1] and the International Energy Agency (IEA) predictions [2] of oil and carbon prices. The final two scenarios consider a combination of high oil prices and moderate carbon prices.

Table 1. Summary of scenarios.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Oil Price** (US$/bbl max by 2030)</th>
<th>GHG (NZ$/t-CO₂ equiv)</th>
<th>New Coal</th>
<th>Hydrogen</th>
</tr>
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<tbody>
<tr>
<td>MEDGreen</td>
<td>130</td>
<td>NZ$25</td>
<td>N</td>
<td>N</td>
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<tr>
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<td>130</td>
<td>$25</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>MEDGrowthFossil</td>
<td>170</td>
<td>100 in 2020</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>IEA450ppm</td>
<td>97</td>
<td>182 in 2030</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>GrowthGreen</td>
<td>130</td>
<td>50</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td>GrowthFossil</td>
<td>170</td>
<td>50</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>GrowthGreenMax&quot;**</td>
<td>130</td>
<td>50</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td>GrowthFossilMax&quot;**</td>
<td>170</td>
<td>50</td>
<td>Y</td>
<td>Y</td>
</tr>
</tbody>
</table>

*Future gas discoveries are assumed an average of 125 PJ per annum of gas production from new discoveries between 2019 and 2030. There are no gas imports or exports.

* Replaces conditional logit with standard logit (see Section 4.1).

** All prices are in real terms.

In the scenario names:
- “Growth” assumes high global demand for oil resulting in an oil price of US$170/bbl by 2030.
- “Green” assumes there is no new coal generation.
- “Fossil” assumes new coal generation is permitted.
- “Max” assumes that consumers place a zero discount rate on capital.

The MEDGreen scenario is detailed in the MED Energy Outlook 2011 [1]. Key parameters for the reference scenario are:
- Oil prices reach US$130 per bbl in 2030.
- An emissions price of $25 per tonne of carbon dioxide is assumed from 2013.
- Two units at Huntly coal fired power station are switched to dry year reserve in 2012 and 2015 respectively. No further coal stations are built.

The MEDFossil is the same as the MEDGreen scenario with the exception that new coal fired generation is allowed and hydrogen vehicles are permitted.

The MEDGrowthFossil scenario assumes oil reaches US$170/bbl by 2030 and the carbon tax $100/tonne-CO₂ by 2020.

The International Energy Agency 450ppm scenario (IEA450) [2] uses the lowest oil price of the scenarios at US$97 per barrel and a very high carbon tax of $182/tonne-CO₂ (US$120) in 2030.

These latter three scenarios of MEDFossil, MEDFossilGrowth and IEA450 are the only scenarios that permit the introduction of hydrogen fuelled ICEVs (H₂ICEV). This option is included for selected scenarios to give an indication of the potential of this technology.
The four remaining scenarios of GrowthGreen, GrowthGreenMax, GrowthFossil, GrowthFossilMax all have an emissions tax of $50/tonne-CO$_2$ in 2030. The oil price for the Green scenarios is US$130/bbl compared to that of the Fossil scenarios of US$170/bbl. The difference lies in whether new coal generation is permitted and whether the conditional or standard consumer choice logit algorithm is used.

Of the eight scenarios examined the GreenGrowth and GreenGrowthMax are closely aligned with the future energy policies of New Zealand with increasing concern in the use and supply security of fossil fuels. These scenarios use similar oil price and emissions tax predictions to the Current Policy Scenario of the World Energy Outlook 2011 [1] that is shown in Figure 1.

![Figure 1. IEA global oil price and production scenarios [2].](image)

* Average IEA crude oil import price.

In the following Section the UniSyD model is first described and then benchmarked against predictions from the MED Energy Outlook 2011 as defined by the MEDGreen scenario.
4 UniSyD and MED Models.

The potential impact of new vehicle technologies on the NZ energy economy must be modelled within a broad scope to ensure that the impacts of fluctuating demands on resources of mutual interest are considered. In order to achieve this under the objectives of this contract and in conjunction with two previous contracts, the UniSyD model of NZ’s energy economy was developed.

The Ministry of Economic Development (MED) operates various models to assist in predicting the energy outlook for the New Zealand energy economy. It uses five distinct but interrelated models [3]. These are:

i. Supply and Demand Energy Model (SADEM). SADEM is a partial equilibrium model of the energy sector with key drivers such as gross domestic product (GDP) and oil price defined exogenously.

ii. Electricity Grid Expansion Model (GEM)

iii. Electricity price forecast model

iv. Oil and gas models

v. Vehicle Fleet Model (VFM).

Unlike the five MED based models UniSyD is a single integrated model that analyses multiple complex demand and supply interactions including the impacts of energy markets, technology integration, energy production, pollution costs, greenhouse gas emissions, generation options and the adoption of new vehicle technologies [4][5].

4.1 Description of UniSyD computer model

A detailed description of the computer code and sector networks for the UniSyD computer model is contained in Leaver et al. (2012) [4]. The model was initiated in 2002 in order to examine the impact of technological advances on New Zealand’s energy economy out to 2050. System dynamics software was chosen for the ability to represent connections between variables by a network diagram.

UniSyD is a system dynamics model of New Zealand’s energy economy. It is a bottom-up model with a high degree of technological specificity. UniSyD version 5.1 [5] contains 50 sectors that are listed in Table 2. This visualisation capability was important in maintaining continuity between various programmers and minimising induction times for new programmers.

UniSyD5.1 models market interactions within 13 different regions of New Zealand. Primary energy sources modelled are coal, natural gas, wind, solar, geothermal and hydro. Resource prices are dynamic as they are determined from supply curves for each resource in each region. The minimization of costs in the 13 regions takes place in four separate markets which are each subject to resource constraints.

The first market is the electricity market that contains detailed performance characteristics for each existing electricity generating facility in New Zealand as well as details for additional technologies likely to be viable to 2050. The optimal generating mix is determined by matching the exogenously set regional electricity demand to the least cost of generation required to meet the demand in that region. Demand in both the electricity and hydrogen markets is forecast on the growth trend on the previous three years and is predicted three
years into the future to provide sufficient time for construction of new generating plant. The cost of generation in each region is then compared with the cost of importing electricity from outside the region to determine the optimum generation mix.

The second market is the hydrogen market. Small scale options for generation in this market include both electrolysis and small scale steam methane reforming located on the forecourts of refilling stations. Large scale options include steam methane reforming, coal gasification, and co-generation of hydrogen and electricity. The large scale options also have a further option of sequestration.

The third market is the lignocellulose market. Lignocellulose is sourced from wood. The optimal use of the resource is determined by the marginal demand to achieve the maximum unit energy price in competition between demand for bioethanol production and biogasification of either hydrogen or electricity production.

The final market is the vehicle market. Existing internal combustion engine vehicles (ICEV) compete with new technologies for market share. Vehicle technologies consist of ICEVs, HEVs, PHEVs, HFCVs, H2ICEVs, BICEVs, and EVs.

Consumer behavior at the time of purchasing a new vehicle is an important factor in determining the composition of the vehicle fleet. This behavior is modelled in UniSyD by a choice of two logit formulae [6]. These are firstly a standard logit and secondly a conditional logit. The difference in the two logit models lies principally in the specification of consumer preference. The standard logit collates consumer preferences into a single variable. However, the conditional logit uses an explicit assessment of the rational factors such as driving range, payback period for increased capital costs from fuel savings, and refuelling infrastructure.

The primary control panel for the model provides for the setting of scenario starting parameters. The modeler can choose one of three technology learning curves for new vehicle technologies. These represent the range of cost reductions extracted from published literature. The year in which the technology is available to consumers is also set along with the current and predicted prices of oil, natural gas and carbon dioxide equivalent. Finally any restrictions on the use of coal as a primary energy source can be specified.

4.2 Modeling constraints
Scenarios and output parameters are necessarily limited in number. The scenarios were selected to provide national (MEDGreen), international (IEA450) and other benchmarks from which to draw broad conclusions on the future of New Zealand’s energy economy. Some assumptions or model perspectives that are worth noting are:

i. The costs of infrastructure for electric vehicle recharging and hydrogen refueling are considered to be the same [7].

ii. All light ICEVs (<3.5 t) are petrol powered and all heavy ICEVs are diesel powered. Further model development is planned to provide for petrol and diesel diversity in the light and heavy fleets.

iii. Shipping, rail and aviation fleets are not included in the model.

iv. Light and heavy vehicle statistics such as the annual distance driven are independent of region.

v. Electricity demand is proportional to population growth.
vi. H₂ICEVs are modelled in only three of the eight scenarios as it is still uncertain whether this technology has a viable future.

vii. Lithium-ion batteries and fuel cells are assumed to last the lifetime of the vehicle without replacement.

viii. Opportunity costs and benefits consider only capital, fuel and emissions costs. In reality other exogenous factors also affect the analysis including vehicle owner hours required for servicing or recharging, pollution costs and infrastructure costs.

ix. The model assumes all vehicle technologies are currently available at the market price appropriate to large scale production. Hence at an oil price of US$170/bbl FCVs are seen to enter the market in 2011 even though it is known that mass production will not commence to 2015. A decision was made not to prevent the model from doing this as it provided better transparency of model dynamics and is reasonable within the context of an uncertain regime of oil and emission prices. This was consistent with the philosophy that the model would contain as few exogenous constraints as possible and that all information would be benchmarked to the best available source. These were usually journal papers, and reports from national and international government sponsored departments or agencies.
4.3  Comparison of MED and UniSyD Results for the MEDGreen Scenario

4.3.1  Electricity generation

Electricity generation profiles to 2040 for MED [1] and UniSyD are shown in Figure 2 (a) and (b) respectively.

![Electricity generation profile (a) MED (b) UniSyD.](image)

In Figure 2a MED predicts increases in geothermal and wind generation by 2040 of 38 PJ and 20 PJ respectively. In Figure 2b UniSyD predicts increases in geothermal and wind generation by 2040 of 20 PJ and 40 PJ respectively.
4.3.2 Wholesale electricity price

Wholesale electricity prices are shown in Figure 3. For MED [1] the wholesale price is an indicator of the future node price at a centrally located electricity node named Haywards.

![Graph showing wholesale electricity price over years for MED and UniSyD](image)

**Figure 3. Wholesale electricity price (a) MED (b) UniSyD.**

In Figure 3a MED predicts that the average wholesale price of electricity to 2040 will be about 10 c/kWh while in Figure 3b UniSyD gives an average wholesale price at the regional gate of 9.7 c/kWh. The wholesale price is affected by both generation capacity and primary resource availability. In addition uncertainty exists around both the productive life and capacity of geothermal fields and the rate of natural gas discoveries.

The spike in costs in Figure 3b around 2029 is a result of increased annual growth due to the rise in plug-in electric vehicles from 2023. The resulting electricity shortage necessitates using coal generation for a short period until more wind and geothermal generation are brought online. Electricity demand for the recharging of electric vehicles rises from 0.85 PJ to 2.45 PJ between 2023 and 2028.

The MED prices are higher than those for UniSyD for two main reasons. Firstly there is a three year difference in the year of assessment with MED being 2011 and UniSyD being 2008. Secondly MED wholesale electricity prices are based on a 2012 resource assessment “2011 NZ Generation Data Update” by Parsons Brinckerhoff whereas those in the UniSyD model are based on those of 2005 East Harbour Management Services Report “Availabilities and Costs of Renewable Sources of Energy for Generating Electricity and Heat.”
4.3.3 Greenhouse gas emissions

Greenhouse gas emissions for MED [1] and UniSyD are shown in Figure 4.

![Figure 4. Greenhouse gas emissions (a) MED (b) UniSyD.](image)

The principal difference in the GHG emissions lies in fuel consumption of the vehicle fleet. UniSyD predicts that the fuel economy of ICEVs will reduce faster than that predicted by MED. The MED model also predicts 58% higher emissions from electricity generation from coal for the period 2013 to 2040. Coal emissions from MED and UniSyD are 19.6 Mt-CO$_{2eq}$ and 12.4 Mt-CO$_{2eq}$ respectively. The difference in emissions is shown in Figure 5.

![Figure 5. Comparative cumulative difference of greenhouse gas emissions between MED and UniSyD.](image)
4.3.4 Transport energy use

Transport energy use for MED [1] and UniSyD is shown in Figure 6.

In Figure 6b UniSyD transport energy projections in 2050 are 30% lower than MED projections in Figure 6a. The difference is mainly attributable to higher predicted improvement in fuel economy in the UniSyD model with a move in ICEV technology to smaller turbo-charged and diesel cycle engines and the introduction of hybridisation into nearly 50% of the light fleet and 38% of the heavy fleet as shown in Figure 7 and Figure 8 and Table 2.

Figure 6. Transport energy use (a) MED (b) UniSyD.

Figure 7. UniSyD light vehicle fleet profile.
Plug-in hybrid vehicles and biofuelled vehicles start to increase their market share significantly in the light fleet from 2025 and 2032 respectively. In the heavy fleet biofuelled vehicles gain significant market share from 2025.
5 Analysis of eight scenarios for the energy outlook

A summary of results for the eight scenarios are shown in Table 3. Detailed graphical outputs are shown in Appendix 1.

5.1 Road transport

5.1.1 Light Fleet

Scenario based fleet profiles are shown in Figure 9.

Figure 9. Light vehicle fleet profiles.

The light road transport fleet will continue to be dominated by ICEVs and HEVs to 2050 with these modes comprising 84% and 75% respectively under the MEDGreen and GrowthGreen scenarios. Under fiscally neutral vehicle incentive policies modelled in the GrowthGreenMax scenario the proportion of ICEVs and HEVs in the light fleet is reduced to 49%.

Under the MEDGreen, GrowthGreen and GrowthGreenMax scenarios FCV fleet penetration is 0%, 9% and 22% respectively. For these three scenarios PHEV penetration ranges from 7%-17% while BICEVs constitute 5%-8%. EVs account for 1% except in the GrowthGreenMax scenario where market share rises to 7%.

In the MEDFossil, MEDGrowthFossil and IEA450 scenarios H2ICEVs constitute about 6% of the light fleet by 2050.
### Table 3. Summary of Key Model Parameters used to Match Scenario End Points.

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Fleet Profile 2050</th>
<th>e &amp; H2 Prices</th>
<th>CO2 eq Emissions</th>
<th>Pollution</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Max Oil Price 2030</td>
<td>Ctax ($/t-CO2)</td>
<td>% ICEV</td>
<td>% BICEV</td>
</tr>
<tr>
<td>MED Green</td>
<td>130</td>
<td>25</td>
<td>Light</td>
<td>34%</td>
</tr>
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<td>MED Fossil</td>
<td>130</td>
<td>25</td>
<td>Light</td>
<td>26%</td>
</tr>
<tr>
<td>MED Growth Fossil</td>
<td>130</td>
<td>100 in 2030</td>
<td>Light</td>
<td>26%</td>
</tr>
<tr>
<td>IEA450</td>
<td>97</td>
<td>182 in 2030</td>
<td>Light</td>
<td>26%</td>
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<tr>
<td>Growth Green</td>
<td>130</td>
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<td>Light</td>
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<tr>
<td>Growth Fossil/Max</td>
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<td>Light</td>
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### Table 4. Hydrogen Production and Electricity Generation

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Hydrogen Production</th>
<th>Electricity Generation</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Max Oil Price 2030</td>
<td>% Electrified</td>
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<tr>
<td>MED Green</td>
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<td>MED Growth Fossil</td>
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<td>100 in 2030</td>
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<td>IEA450</td>
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<td>Growth Fossil/Max</td>
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<td>50</td>
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</table>
5.1.2 Heavy Fleet

The heavy road transport fleet will continue to be dominated by ICEVs and HEVs to 2050 with these modes comprising 65% and 58% respectively under the MEDGreen and GrowthGreen scenarios. BICEVs comprise 28% of the fleet in 2050 for these scenarios. Under fiscally neutral vehicle incentive policies modelled in the GrowthGreenMax scenario the proportion of ICEVs and HEVs in the heavy fleet is 66%. However the proportion of BICEVs reduces to 16%.

Under the MEDGreen, GrowthGreen and GrowthGreenMax scenarios FCV fleet penetration is 0%, 8% and 14% respectively. For these three scenarios PHEV penetration ranges from 5%-7% while BICEVs constitute 16%-28%. Most heavy PHEVs are likely to be made up of vehicles at the lighter end of the heavy classification and operated from a central depot. The proportion of BICEVs in the heavy fleet is typically more than double the proportion of the light fleet due to the fact that the fuel costs for heavy vehicles are a larger proportion of the overall annual cost.

In the MEDFossil, MEDGrowthFossil and IEA450 scenarios H2ICEVs constitute about 6% of the heavy fleet by 2050.

5.2 Energy sector greenhouse gas emissions and pollution costs

Scenario based GHG reductions for 2010 to 2050 are shown in Figure 10.

Figure 10. Scenario based GHG reductions.

In Figure 10 the reduction in GHG emissions for the period 2010-2050 across all eight scenarios ranges from 35% for IEA450 and MEDGrowthFossil to -17% for MEDFossil. The average reduction in GHG emissions for the period 2010-2050 across all scenarios is 21%. MEDFossil GHG emissions are significantly higher than any other scenario due to the increase in coal generation after 2025 that is facilitated by a low carbon tax of $25/t-CO2eq.
5.3 Electricity generation

Electricity generation profiles in 2050 are shown in Figure 11.

Figure 11. Electricity generation profiles in 2050 for modes with greater than 3% of total generation.

Hydro generation remains in the narrow range of 37% to 40% across all scenarios due to the limited capacity for new hydro and the comparatively low operating costs of existing hydro.

Wind generation ranges from 11% in MEDFossil to 33% for MEDGrowthFossil. The fourfold increase in carbon price from $25/tonne-\(\text{CO}_2\) in 2020 in MEDFossil to $100/tonne-\(\text{CO}_2\) in 2020 in MEDGrowthFossil results in a threefold increase in the proportion of wind generation.

Geothermal is a very competitively priced option for base load generation and remains within the range of 14% to 19%.

Gas generation is 4% under IEA450 with a carbon tax of $182/tonne-\(\text{CO}_2\) by 2030 but rises to 10% - 12% under scenarios where the carbon tax is $50/tonne-\(\text{CO}_2\) or less.

Coal generation remains less than 5% due to either a carbon tax at or above $50/tonne-\(\text{CO}_2\) or due to a prohibition on building new coal plant. Under the MEDFossil scenario the carbon tax is a low $25/tonne-\(\text{CO}_2\) that facilitates coal generation reaching 19%.

As shown in Figure 12 significant cogeneration of electricity and hydrogen amounting to 7% occurs only in the GrowthFossilMax scenario under fiscally neutral incentives for encouraging the purchase of alternative vehicles. This scenario has the greatest proportion of light and heavy FCVs in 2050 at 24% and 31% respectively.
Figure 12. Electricity generation for the GrowthFossilMax scenario.

The proportion of renewable generation is shown in Figure 13.

Figure 13. Renewable energy generation in 2025 and 2050.

Renewable generation across all scenarios increases by an average of 3% from 79% to 82% between 2020 and 2050. Two scenarios record a drop in renewable generation during this period.

As shown in Figure 14 for the MEDFossil scenario the low carbon tax of $25/tonne-CO₂ allows coal to remain competitive with significant coal generation occurring between 2022 and 2050.
Figure 14. Electricity generation for the MEDFossil scenario.

In Figure 15 showing the GrowthFossil scenario with a carbon tax of $50/tonne-CO\textsubscript{2} coal generation is also significant between 2025 and 2040. Coal loses market share to wind after 2040 and reduces to 4% by 2050.

Figure 15. Electricity generation for the GrowthFossil scenario.
5.4 Hydrogen generation

A summary of generation of hydrogen generation is shown in Figure 16.

Figure 16. Hydrogen generation by scenario.

Figure 17. Hydrogen generation profiles.
No hydrogen is generated in the MEDGreen scenario as no hydrogen vehicles are permitted. Of the remaining scenarios electrolysis or small scale steam methane reforming are the dominant forms of hydrogen generation with the exception of the GrowthFossilMax scenario where the high hydrogen demand for both light and heavy FCVs that constitute 24% and 31% respectively of the vehicle fleet by 2050 permits the building of large scale coal cogeneration plant that includes carbon sequestration.

Profiles of hydrogen production of four scenarios are shown in Figure 17. Features of the profiles are firstly the dominance of forecourt small scale steam methane reforming in IEA450, secondly the dominance of electrolysis in GrowthGreenMax where the use of new fossils is prohibited and finally the short transition in GrowthFossilMax from electrolysis and small scale steam methane reforming to large scale coal based cogeneration of hydrogen and electricity.

5.5 Wholesale electricity and hydrogen prices
Wholesale electricity prices are shown in Figure 18. As New Zealand has a large resource base of renewable energy, prices are predicted to remain at about 10c/kWh (2008 dollars) to 2050. Prices exclude any large upgrade in service and reliability of the transmission system. If this occurred the wholesale price of electricity could increase above that predicted. The high wholesale price that peaks at 30c/kWh during the period 2012 to 2014 under the GrowthGreenMax scenario is due to a very short term shortage of renewable generating capacity prompted by an unforeseen increase in the production of hydrogen by electrolysis. The price drops as soon as more wind generation is brought into the system.

Figure 18. National wholesale electricity price.
Wholesale hydrogen prices are shown in Figure 19. Prices for volumes less than a kilotonne per annum are nominally set at $6.5/kg and represent the cost of production of small volumes. In 2050 the price of hydrogen in the North Island ranges from $5.70 to $7.86 under all scenarios except for the GrowthFossilMax for which the price is $4.96. This reduction results from the use of coal based cogeneration technology as opposed to the electrolysis used in the GrowthGreenMax scenario.

Figure 19. National wholesale hydrogen price.
6 Opportunity costs

The opportunity costs or savings associated with hydrogen fuel cell vehicles is examined in relation to the GrowthGreen and GrowthGreenMax scenarios. The difference between the scenarios is that in GrowthGreen capital expenditure is weighted about twice as highly with consumers as operational expenditure whereas in the GrowthGreenMax scenario there is no difference in weighting. These scenarios were rerun on UniSyD but no FCVs were permitted. The opportunity costs for the scenarios with and without FCVs were then compared to identify the benefits of permitting FCVs in the fleet. All of the scenarios also permitted HEVs, PHEVs and EVs. The particular parameters examined are capital cost of the fleet, fuel cost of the fleet, carbon tax revenue and volume of petrol and diesel used by the fleet.

6.1 GrowthGreenMax (Standard logit)

The cumulative fuel saving for petrol and diesel along with the modelled fuel price is shown in Figure 20. The savings rise rapidly from 2013 coinciding with the uptake of FCVs. Savings average about 480 ML per year.

![Figure 20. Cumulative opportunity fuel saving in petrol and diesel.](image)

![Figure 21. Cumulative opportunity saving of capital cost of the fleet, fuel cost of the fleet, and carbon tax revenue.](image)
The cumulative opportunity saving of capital cost and fuel cost of the fleet, and carbon tax revenue is shown in Figure 21. The adoption of FCV technology increases the annual capital investment in the fleet by about $140 million to a maximum cumulative addition of about $5.3 billion in 2034. However this is more than offset by average annual savings in fuel and carbon taxes to 2050 of $210 million and $45 million respectively. The cumulative net opportunity saving is $4.3 billion by 2050.

The average annual saving in GHG emissions is 900 kt-CO$_{2}$eq.

6.2 GrowthGreen (Conditional logit)

The cumulative fuel saving for petrol and diesel along with the modelled fuel price is shown in Figure 22. The savings rise rapidly from 2013 coinciding with the uptake of FCVs. Savings average about 220 ML per year.

![Figure 22. Cumulative opportunity fuel saving in petrol and diesel.](image)

The cumulative opportunity saving of capital cost and fuel cost of the fleet, and carbon tax revenue is shown in Figure 23. The adoption of FCV technology increases the annual capital
investment in the fleet to 2050 by about $130 million to a maximum cumulative addition of about $4.8 billion in 2050. However this is more than offset by average annual savings in fuel and carbon taxes to 2050 of $120 million and $30 million respectively. The cumulative net opportunity saving is $1.1 billion by 2050.

The average annual saving in GHG emissions is 600 kt-CO$_2$eq.

### 6.3 Scenario comparison

The cumulative opportunity saving for GreenGrowth and GreenGrowthMax scenarios for oil prices in 2030 of US$130/bbl and US$170/bbl is shown in Figure 24.

![Figure 24. Cumulative opportunity saving for GreenGrowth and GreenGrowthMax scenarios for oil prices in 2030 of US$130/bbl and US$170/bbl.](image)

The increase in oil in 2030 of US$40/bbl results in an average additional cumulative opportunity saving to 2050 for the scenarios of $3 billion. Overall the adoption of FCV technology returns a net opportunity saving of between $1.1 billion and $4.3 billion by 2050 for an oil price of US$130/bbl from 2030. This saving rises to a maximum $8.4 billion for an oil price of US$170/bbl from 2030.
7 References


8 Comparative Graphical Outputs to 2050 for Eight Scenarios
National Hydrogen Production

MEDGreenHydrogen Production

MEDFossilHydrogen Production

MEDGrowthFossilHydrogen Production

IEA450Hydrogen Production
National Hydrogen Price

- MEDGreen Hydrogen Price
- MEDFossil Hydrogen Price
- MEDGrowthFossil Hydrogen Price
- IEA450 Hydrogen Price
Heavy Vehicles

MEDGreen Heavy Vehicles

MEDFossil Heavy Vehicles

MEDGrowthFossil Heavy Vehicles

IEA450 Heavy Vehicles
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