Technical Guide

Energy Outlook Modelling

Version 1.0

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**** Some sections are incomplete – new versions will be released on the MED website as each new section is completed***

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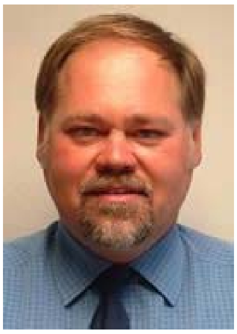
	**Mark Walkington** Transport, SADEM and emissions modelling DDI 04-474 2978 mark.walkington@med.govt.nz

The team is happy to field queries/comments/suggestions relating to energy modelling

Contents

1 Overview

The Ministry of Economic Development's (MED) current approach to energy modelling for the Energy Outlook uses five distinct but interrelated models:

- Supply and Demand Energy Model (SADEM),
- electricity Grid Expansion Model (GEM),
- electricity price forecast model,
- oil and gas models, and the
- Vehicle Fleet Model (VFM).

These models are used to produce forecasts of energy supply and demand and energy sector greenhouse gas emissions.

Within this approach SADEM performs three key functions. Firstly, it projects energy demand for all sectors of the economy (with the exclusion of land transport) using econometric relationships with exogenous drivers (such as GDP and population) and relative price levels. Secondly, it provides a central hub, coordinating electricity supply information from GEM and land transport demand information from the VFM. Finally, SADEM calculates projections of energy sector greenhouse gas emissions by applying emission factors. This final stage also includes some realigning of the information to Intergovernmental Panel on Climate Change Convention (IPCCC) categories for National Greenhouse Gas Emissions Inventory reporting.

The projections of on road transport energy demand from the VFM are "bottom-up" forecasts. This bottom up modelling produces detailed fleet projections based on historical relationships of the fleet (turn-over, kilometres travelled, efficiency improvements, engine size and fuel switching) to economic growth, population change and fuel prices, and forecasts of these key exogenous variables. With the exception of using the same exogenous variables there is no real interactive feedback link between SADEM and the VFM meaning that the VFM essentially provides "plug and play" projections of land transport demand to SADEM.

The electricity GEM model is a "Mixed integer program" (MIP) which finds the lowest cost combination of new generation plant to build over the forecast horizon. The new generation build must be sufficient to meet the demand forecast produced by SADEM. GEM also calculates the future gas demand from existing and new thermal plant, and this gas demand feeds through to SADEM (SADEM totals up all gas demand which must be in balance with the gas production forecasts). The new build schedule produced by GEM is also used calculate a future wholesale electricity price in a separate model. Future prices are assumed to cover the Long Run Marginal Cost (LRMC) of the newly installed plant.

There are two oil and gas models:

- a simulation model of future exploration activity which produces a probability distribution of future oil and gas discoveries, and a
- financial model which determines whether these discoveries meet commercial thresholds.

The financial model is used to produce a gas supply curve based on the "breakeven[1]" gas price for each discovery. The gas supply curve feeds through to SADEM and the equilibrium gas price is determined where total demand intersects the supply curve.

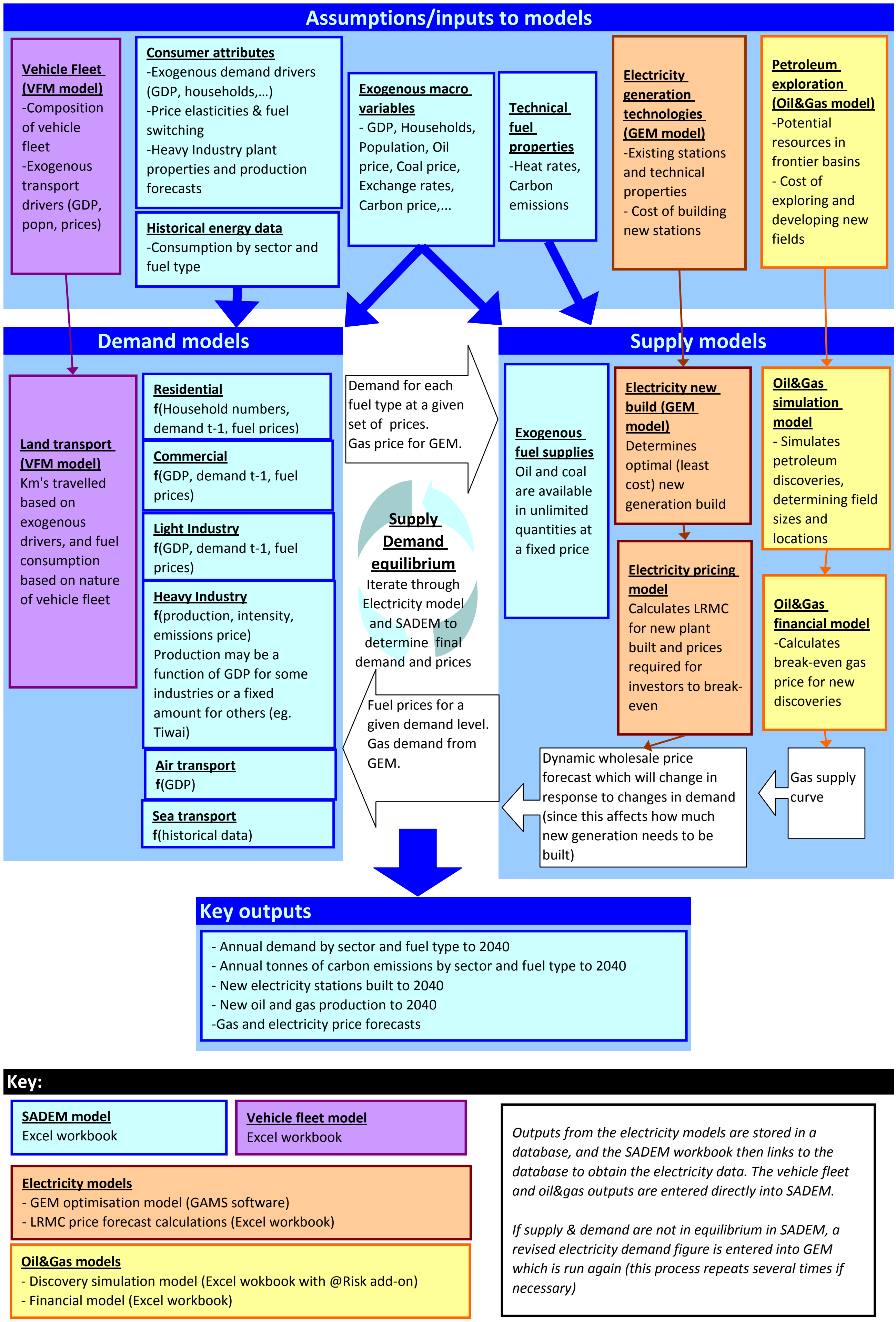
The GEM SADEM interface is a dynamic loop within this modelling system. GEM requires inputs of fuel prices and electricity demand forecasts from SADEM. The demand forecasts in SADEM are based on relative fuel prices, including electricity prices. However the electricity price forecast is produced from the GEM build schedule which is, in turn, affected by the demand from SADEM. This produces a loop which becomes an iterative process to determine equilibrium between the electricity supply produced by GEM and the demand for electricity produced by SADEM.

This entire modelling system is based on a set of relationships based on observed past behaviour, engineering estimates, costs of technologies and the behaviours of market participants. Models are useful to help frame expectations of the future, but they do however have limitations. In particular:

- The future is uncertain and modelling cannot take into account the subtleties of commercial decision-making or barriers to investment.
- The models are based on what we have observed in the past and the present. However the relationship between energy demand and its key drivers may change in the future, particularly if there are unexpected changes in technology or external shocks.
- This modelling is of the energy sector only, not of the entire economy. Key drivers within this modelling are exogenous (for example GDP and oil price) meaning that secondary effects are not modelled, e.g. the potential link between the price of oil and GDP is not taken into account.

The following diagram outlines the key interactions in MED's energy modelling system. It is only intended to provide a high level picture of the system. In reality there are many more complex linkages within the system and the following technical document provides more detail around each of the sub models and the linkages between them.

[1] Breakeven gas price is the price at which the Net Present Value (NPV) of the project equals zero.


Assumptions/inputs to models
Vehicle Fleet (VFM model)
-Composition of vehicle fleet
-Exogenous transport drivers (GDP, popn, prices)
Consumer attributes
-Exogenous demand drivers (GDP, households,…)
-Price elasticities & fuel switching
-Heavy Industry plant properties and production forecasts
Historical energy data
-Consumption by sector and fuel type
Exogenous macro variables
- GDP, Households, Population, Oil price, Coal price, Exchange rates, Carbon price,…
Technical fuel properties
-Heat rates, Carbon emissions
Electricity generation technologies (GEM model)
-Existing stations and technical properties
- Cost of building new stations
Petroleum exploration (Oil&Gas model)
-Potential resources in frontier basins
- Cost of exploring and developing new fields
Demand models
Land transport (VFM model)
Km's travelled based on exogenous drivers, and fuel consumption based on nature of vehicle fleet
Residential
f(Household numbers, demand t-1, fuel prices)
Commercial
f(GDP, demand t-1, fuel prices)
Light Industry
f(GDP, demand t-1, fuel prices)
Heavy Industry
f(production, intensity, emissions price)
Production may be a function of GDP for some industries or a fixed amount for others (eg. Tiwai)
Air transport
f(GDP)
Sea transport
f(historical data)
Demand for each fuel type at a given set of prices.
Gas price for GEM.
Supply Demand equilibrium
Iterate through Electricity model and SADEM to determine final demand and prices
Fuel prices for a given demand level.
Gas demand from GEM.
Supply models
Exogenous fuel supplies
Oil and coal are available in unlimited quantities at a fixed price
Electricity new build (GEM model)
Determines optimal (least cost) new generation build
Electricity pricing model
Calculates LRMC for new plant built and prices required for investors to break-even
Oil&Gas simulation model
- Simulates petroleum discoveries, determining field sizes and locations
Oil&Gas financial model
-Calculates break-even gas price for new discoveries
Dynamic wholesale price forecast which will change in response to changes in demand (since this affects how much new generation needs to be built)
Gas supply curve
Key outputs
- Annual demand by sector and fuel type to 2040
- Annual tonnes of carbon emissions by sector and fuel type to 2040
- New electricity stations built to 2040
- New oil and gas production to 2040
-Gas and electricity price forecasts
Key:
SADEM model
Excel workbook
Vehicle fleet model
Excel workbook
Electricity models
- GEM optimisation model (GAMS software)
- LRMC price forecast calculations (Excel workbook)
Oil&Gas models
- Discovery simulation model (Excel wokbook with @Risk add-on)
- Financial model (Excel workbook)
Outputs from the electricity models are stored in a database, and the SADEM workbook then links to the database to obtain the electricity data. The vehicle fleet and oil&gas outputs are entered directly into SADEM.
If supply & demand are not in equilibrium in SADEM, a revised electricity demand figure is entered into GEM which is run again (this process repeats several times if necessary)

2 Supply and Demand Energy Model (SADEM)

2.1 Exogenous data

Gross Domestic Product

Economic growth drives energy demand in the commercial and industrial sectors. The central GDP forecast is sourced from The Treasury. The model uses a GDP index normalised to 1000 based on GDP production[2] with 1983 as the base year.

Exchange Rates

The US to NZ exchange rate is used in SADEM as part of the calculation of petrol and diesel prices (in New Zealand dollars) from forecasts of international oil prices in US dollars. It is also used to convert the capital costs of building new electricity plant in the GEM model.

Emissions price

In the model the emissions price affects the costs of fossil fuels, which affects fuel demand and the economics of fossil fuelled electricity generation.

The emissions price is currently based on the global emissions price expected to result from a more stringent emissions target. It assumes "comparable efforts by other countries" and "a pathway to limit global temperature rises to not more than 2C".

An emissions price of $50 /tonne for the 2012 – 2020 period is currently used across agencies (MfE, Treasury, MED) – for modelling NZ's Kyoto Protocol Net Position.

Population and household numbers

Population and household number projections are sourced from Statistics NZ. Household numbers are used to help forecast residential demand while population projections are used in the Transport demand modelling. The 2010 Reference Scenario uses the Medium Fertility, Medium Mortality and Medium Migration series.

[2] As opposed to GDP expenditure.

2.2 Historical demand and activity data

SADEM uses the historical energy data published in MED's annual *Energy Data File*. To the extent possible, all forecasts are produced on the same basis as the historical data. That is, definitions of sectors and energy types are aligned across the historical and forecast data. This is often challenging given the various international standards for reporting for energy statistics and greenhouse gas emissions.

2.3 Residential, Commercial and Light Industry Demand

The generic forecasting equations

These models have different exogenous drivers and different parameters, however the basic construction of each model is identical. Outlined below is the sequence of equations used to produce a final demand forecast in one of these sectors.

The first step is to forecast the "effective" energy demand which is the net petajoules (PJ) of energy consumed (as opposed to the PJ of fuel consumed which needs to take into consideration the "efficiency" of each fuel). The effective demand forecast is based on an econometric relationship with an exogenous driver and an autoregressive parameter is also used due to the strong autocorrelation in the historical series.

(1) $\text{Effective\_energy}_{s,t} = \exp\{ \beta_{1,s} * \ln(\text{Exog}_{s,t}) + \beta_{2,s} * \ln(\text{Effective\_energy}_{s,t-1}) + \text{Constant}_s \}$

where $\text{Exog}_{s,t}$ is the exogenous driver for sector s in year t,

exp is the natural exponential function,

and ln is the natural log.

The sectors (s) are Residential, Commercial and Light Industry. The following table shows the exogenous drivers for each.

Table 1 Demand model drivers

Sector	Exogenous driver	$\beta_{1,s}$	$\beta_{2,s}$	Constant_s
Residential	Household numbers	.62	.38	-.65
Commercial	GDP	.38	.48	-.97
Light Industry	GDP	.35	.18	.6

The remaining equations calculate how this effective energy demand is broken down into demand for the alternative fuels. This is where we introduce the prices for each fuel type (electricity, gas, coal, diesel, petrol and fuel oil).

(2) $\text{Unadj\_mkt\_share}_{f,s,t} = \text{Base\_mkt\_share}_{f,s} * (\text{Price}_{f,s,t}\text{\^{}Mkt\_elasticity}_s / \text{Price}_{f,s,base}\text{\^{}Mkt\_elasticity}_s)$

where $\text{Unadj\_mkt\_share}_{f,s,t}$ is the unadjusted market share for fuel f, sector s and year t,

$\text{Base\_mkt\_share}_{f,s}$ is the market share in the base year, in this case 2008, and

$Mkt\_elasticity_s$ is the elasticity parameter reflecting the degree of fuel switching in response
to relative price changes.

At this point when we sum the market shares across the fuels we will get a number less than 1 if all fuel prices have increased relative to their base years. Since equation (2) is focused only on fuel switching, we need to make a pro-rata adjustment so that the market shares sum to 1. This is outlined in equation (3) which also introduces a lag parameter, Mkt_lag_s, which has a value between 0 and 1.

$$(3)\ Adj\_mkt\_share_{f,s,t} = (1 - Mkt\_lag_s) * (Unadj\_mkt\_share_{f,s,t} / \Sigma Unadj\_mkt\_share_{s,t}) + Mkt\_lag_s * Adj\_mkt\_share_{f,s,t-1}$$

We can then apply the market share percentages in (3) to the effective energy demand in (1) to get a preliminary demand for each fuel:

$$(4)\ Prelim\_demand_{f,s,t} = Adj\_mkt\_share_{f,s,t} * Effective\_energy_{s,t} / Efficiency_f$$

where $Efficiency_f$ is the efficiency with which fuel (f) can be converted to energy.

The final demand equation introduces a "fuel conservation" effect via the price elasticity parameter "$Price\_elasticity_s$". This elasticity parameter allows total fuel demand to reduce in response to increasing prices (as opposed to the parameter $Mkt\_elasticity_s$ which was just concerned with relative market shares of the fuels). Equation (5) also introduces another lag parameter, $Price\_lag_s$.

$$(5)\ Final\_demand_{f,s,t} = Prelim\_demand_{f,s,t} * \{(Price_{f,s,t}/Price_{f,s,base})\text{^}Price\_elasticity_s\} * \{ (Final\_demand_{f,s,t-1} / Prelim\_demand_{f,s,t-1})\text{^}\ Price\_lag_s\}$$

The following table shows the elasticity and lag parameter values for each sector.

Table 2 Demand model elasticities

Sector	$Mkt\_elasticity_s$	Mkt_lag_s	$Price\_elasticity_s$	$Price\_lag_s$
Residential	-0.5	0.2	0.0	0.2
Commerical	-0.5	0.5	-0.01	0.5
Light Industry	-0.5	0.5	-0.05	0.5

Omitted from the above equations are some additional calculations relating to the direct use of gas. If total gas demand is greater than total production then the demand for gas can be scaled back so that gas supply and demand are in equilibrium. If gas is scaled back then we assume there will be offsetting increases in coal and electricity demand (these assumptions differ for each sector as shown in the below table). In the Reference Scenario we assume the gas demand is scaled back by 20% from 2027.

Table 3 Redistribution of gas

	Heavy Ind	Light Ind	Commercial	Residential
Electricity	70%	80%	90%	95%
Coal	30%	20%	10%	5%
Gas	-100%	-100%	-100%	-100%

Estimating the elasticity and fuel switching parameters

To come.

2.4 Heavy Industry Demand

To come.

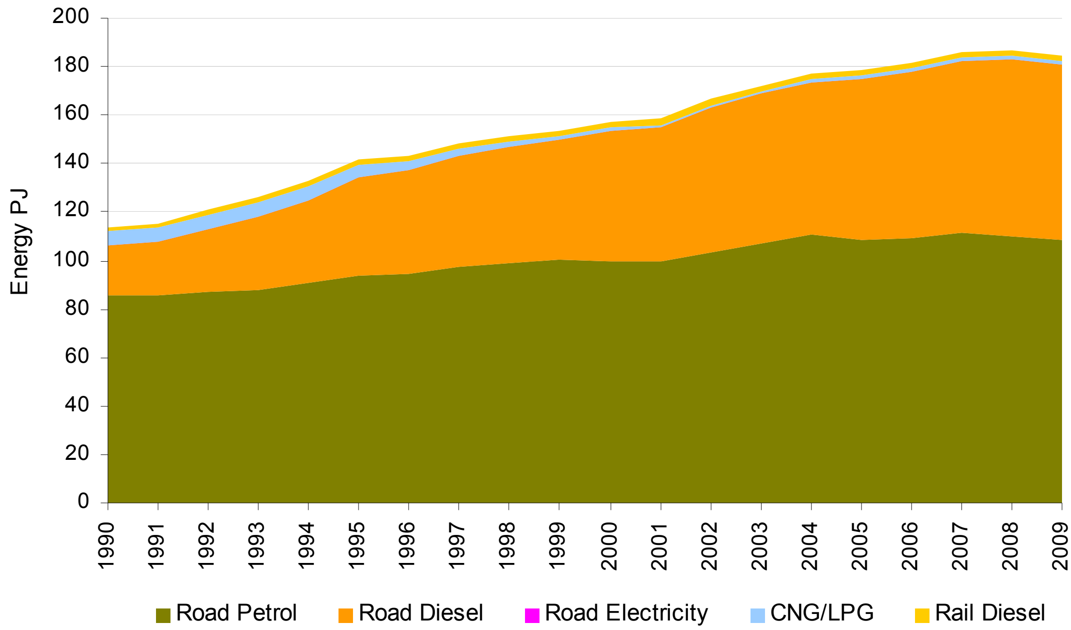
2.5 Land Transport Demand

Land transport includes that made on foot, by cycle, horse, motorcycle, motor vehicle and by rail. It includes personal transport and the movement of freight. In terms of energy statistics the focus is on road and rail (with some of those other modes somewhat difficult to measure). The vast majority of vehicles used to provide this transport are propelled by oil products particularly petrol and diesel and LPG. Electricity is used for some rail and in 2009 for a handful of electric cars and trolley buses.

While transport accounts for the majority of oil product use, there are also a range of non-transport uses of these fuels. These include stationary applications, such as fuel burned in generators, fuel used for heating, gardening equipment etc; and mobile applications off-road. Transport energy does not include that used by motorised vehicles in off-road situations such as on farm or at construction sites; fuel known to be delivered for these purposes is recorded under the various economic sector titles. Pragmatically it is hard to differentiate the amount of fuel sold at service stations between its final end-uses (e.g. petrol taken home for lawn mowing) and thus all of such fuel and energy is allocated to transport.

MED's energy statistics identify consumer energy by fuel and by end-use sector. Transport energy is recorded as the sum of fuel sold directly to transport sector participants and all fuel sold at retail service stations and truck stops. Sea transport energy is inferred as the sale of fuel oil to the transport sector and air transport energy is inferred as the total of jet fuel and aviation gasoline. Land transport is allotted all petrol, diesel and LPG less that sold directly to non-transport participants.

Figure 1 Land transport energy demand - by fuel type



Note the strong growth in diesel demand throughout and the dwindling level of CNG/LPG after the peaks reached in the 1980s when governments actively encouraged these alternatives. The growth in diesel followed earlier deregulation of the freight industry and the almost total move away from gasoline powered trucks and light commercial vehicles.

It is also worth making note of the plateau reached in petrol demand over the last 4 years – a period of higher fuel prices and the recession over 2008-09. Petrol demand reached a peak in 2004 with demand dropping over the last 3 years.

Issues have arisen in the past because of a lack of information as to the final end-user of a proportion of our diesel but a new survey of fuel distributors has shed additional light as to the amount of this fuel used off-road. In 2009 the MEDs Energy Data File's Balance Table shows an estimate of 30PJ of diesel used off road with 75.1PJ used in transport.

2.5.1 Road

The projections of land transport energy demand from the VFM are "bottom-up" forecasts. This bottom up modelling produces detailed fleet projections based on historical relationships of the fleet (turn-over, kilometres travelled, efficiency improvements, engine size and fuel switching) to economic growth, population change and fuel prices, and forecasts of these key exogenous variables.

VFM essentially provides "plug and play" projections of land transport demand to SADEM. For more details refer to section 5 ***Road Transport – Vehicle Fleet Model*** later in this document.

2.5.2 Rail

Information on the energy use by New Zealand railways is derived from information provided by KiwiRail (and its predecessors). This data is utilised to calculate the greenhouse gas emissions from rail, published each year in the MED publication, *New Zealand Energy Greenhouse Gas Emissions*.

These emissions result from the combustion of diesel used to power diesel-electric locomotives. The amount of fuel used has been relatively flat since 1995 however our *Reference Scenario* projection allows for this demand to increase in line with expected economic growth

i.e. $\text{Energy}_{\text{rail}} \sim f$ (historical data, GDP)

Indeed, KiwiRail intends to expand its operation in the future but they are also purchasing new locomotives which may be expected to provide some energy efficiency improvement. We have also incorporated an allowance for the electrification of Auckland's commuter rail expected by 2015 to reduce diesel demand there by around 10 million litres per annum. Rail's total energy demand at just over 2PJ in 2009 contributes less than 1% of New Zealand's total transport energy demand.

2.6 Air Transport Demand

To come.

2.7 Sea Transport Demand

To come.

2.8 LPG Demand

To come.

2.9 Greenhouse Gas Emissions

To come.

2.10 Energy Intensity

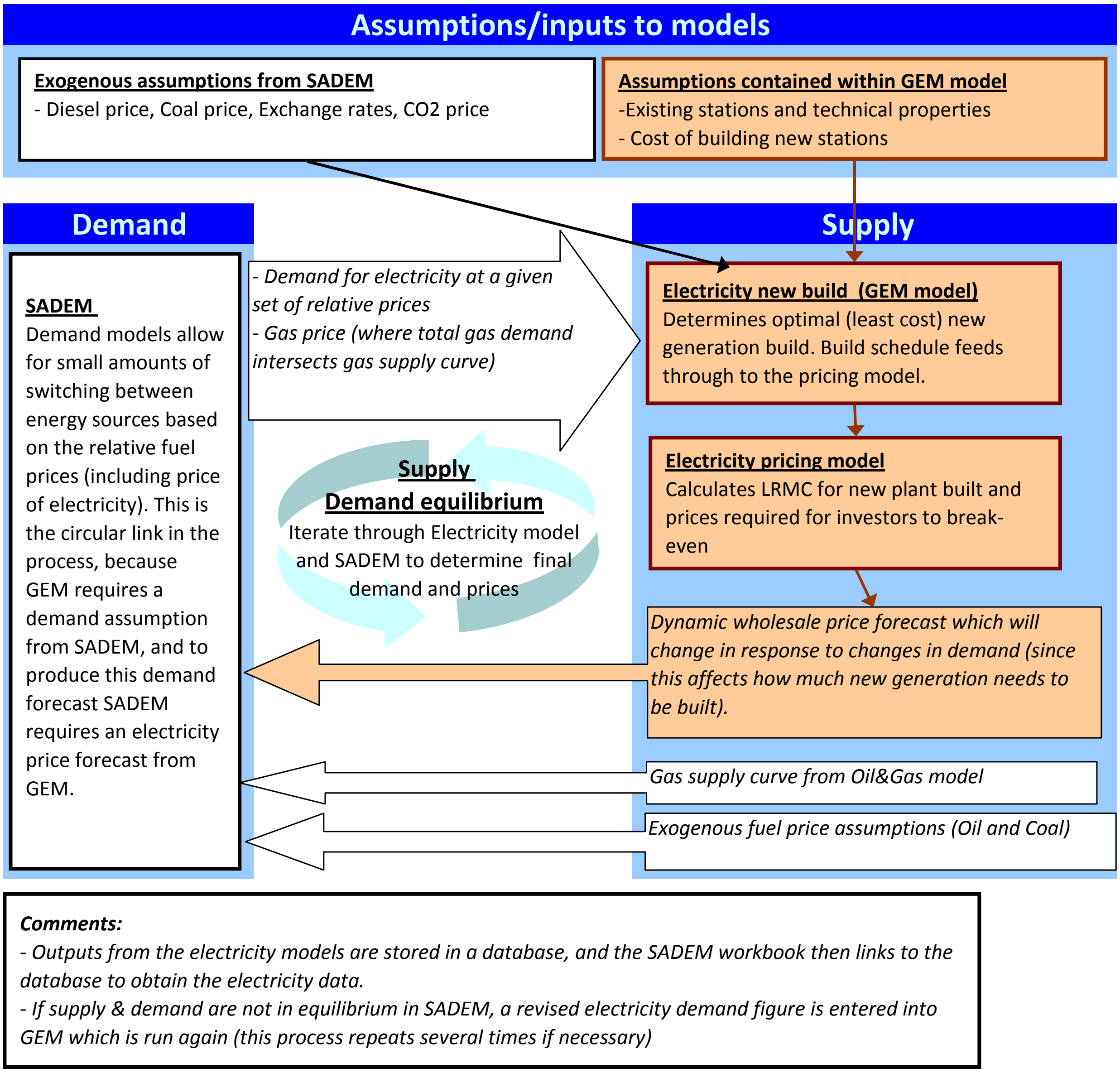
To come.

3 Electricity Supply and Prices

3.1 Overview

The GEM[3] optimisation model produces a forecast of new generation plant built over the next 30 years and the expected gas demand from existing and new thermal generators. A separate pricing model then determines the wholesale price forecast based on the LRMC (long run marginal cost) of each new plant built. These models operate independently of SADEM however data is exchanged between all the models in a dynamic loop. *Figure 2* outlines the nature of these linkages.

Figure 2 Interactions between SADEM and Electricity models



[3] Grid Expansion Model

GEM requires inputs of fuel prices and electricity demand forecasts from SADEM. The demand forecasts in SADEM are based on relative fuel prices, including electricity prices. However the electricity price forecast is produced from the GEM build schedule which is, in turn, affected by the demand from SADEM. This produces a loop which becomes an iterative process to determine an equilibrium between the electricity supply produced by GEM and the demand for electricity produced by SADEM.

3.2 GEM model

3.2.1 GEM overview

The generation expansion model (GEM) has been developed by Phil Bishop at the Electricity Authority (EA) and can be downloaded at http://code.google.com/p/gem/downloads.

GEM determines the new generation plant that needs to be built over the next 30 years in order to meet demand growth and retirement of existing plant. It determines:

- what technology gets built (wind / hydro / geothermal / thermal baseload / thermal peakers),
- when it gets built,
- how much gets built (MW), and
- where it gets built (North island / South Island).

GEM models both energy demand (GWh) and peak demand (MW) growth and so the new generation built must be sufficient to meet both energy and peak requirements. Accordingly, when GEM chooses what plant is built, it is choosing between plant which is primarily for baseload operation (e.g. geothermal, wind, combined cycle gas turbine (CCGT)) or plant that is designed primarily for meeting peak demand and/or supply shortfalls such as dry years or windless days (e.g. open cycle gas turbine (OCGT)).

In making the decision to build new plant, GEM samples from a list of possible new generation projects and then calculates the total cost from building each combination of new plant (capital and operating costs). GEM iterates through until it finds the **lowest cost** combination of new plant to meet the various model constraints (the key constraint being energy and peak demand growth).

It is important to note that GEM is purely a cost minimisation model. It does not consider the commercial objectives of individual market participants and nor does it consider the likelihood of various projects proceeding. However, the model user can apply some discretion by preventing the build of certain projects until a certain year, or even “forcing in” a project in a certain year.

GEM also models the HVDC transmission link between the North and South Island, so when making new build decisions (and the location) will consider the transmission capacity (MW) available between the islands.

There are many more layers of detail in the GEM model which go beyond the scope of this document. The EA's website[4] and the GEM wikipage[5] have more information about the model. The following extract is taken from the EA website:

"The Authority's generation expansion model (GEM) is a capacity expansion model of the New Zealand electricity sector. GEM models a wide range of large-scale electricity generation technologies, including: thermal, wind, hydro and wave.

GEM is a mathematical programming (i.e. optimisation) problem of the mixed integer program (MIP) type. It is coded using the GAMS software and is solved with the CPLEX solver (although alternative MIP/LP solvers could be used).

Matlab scripts are included for processing GEM output files and generating various plots. In addition, compiled versions of the Matlab scripts have been included for users who don't have Matlab installed on their computers. However, in order to use the compiled Matlab scripts, it is necessary to download and install the Matlab Component Runtime (MCR) file below. We recommend obtaining the MCR from here to ensure compatibility with the compiled Matlab scripts.

In the interest of transparency and openness, the Authority is pleased to make the GEM programs and data files freely available. It is distributed under the terms of the GNU General Public License. This means it may be freely used, modified and distributed. However, the GEM software carries no warranty, either expressed or implied, and the Authority cannot be held liable for losses arising from any decisions based entirely or in part on GEM results. The GNU General Public License does not apply to the GAMS, CPLEX or Matlab software. Users are expected to purchase their own licenses for the software required to operate GEM."

3.2.2 GEM assumptions

Although the GEM equations are written using the GAMS software, most of the key assumptions are contained in an Excel workbook. This workbook can be downloaded at http://code.google.com/p/gem/downloads. The key assumptions contained in the workbook are:

- the list of all possible new generation plant that could be built;
- the capital costs and operating costs associated with each plant;
- technical operating specifications for each plant (such as heat rate for thermal plant, expected capacity factors for windfarms,...);
- fuel availability and cost; and
- carbon emissions cost.

The 2010 Outlook uses the Excel workbook as a starting point for determining the detailed electricity assumptions, however, there are a few areas where the MED view may differ slightly.

[4] http://www.ea.govt.nz/industry/modelling/in-house-models/gem/

[5] https://gemmodel.pbworks.com/w/page/12530057/Overview

Gas availability (PJ pa) is an assumption that comes from SADEM. It is estimated by subtracting non-electricity usage from the total gas production (refer also to section 4 for details of the gas supply modelling).

The gas price also comes directly from SADEM. It is determined where total gas demand intersects the supply curve (again, refer to the separate gas modelling section for more details).

Other assumptions that come from SADEM are the diesel price, coal price, carbon price and exchange rate.

Some of the capital cost assumptions have been adjusted by MED where we may have more recent information direct from generators or a different view of the costs. A comprehensive review of capital and operating costs will be undertaken by MED in 2011 (from 2011 MED takes responsibility for compiling the assumptions for the "Statement of Opportunities" or SOO).

3.2.3 GEM outputs: Reference scenario 2010

There are a wide range of outputs produced after a GEM model run. The key outputs which feed through to SADEM are:

– new generation build schedule;

– gas consumption (PJ per annum); and

– annual generation (GWh).

Figure 3 New plant built in the Reference Scenario 2010

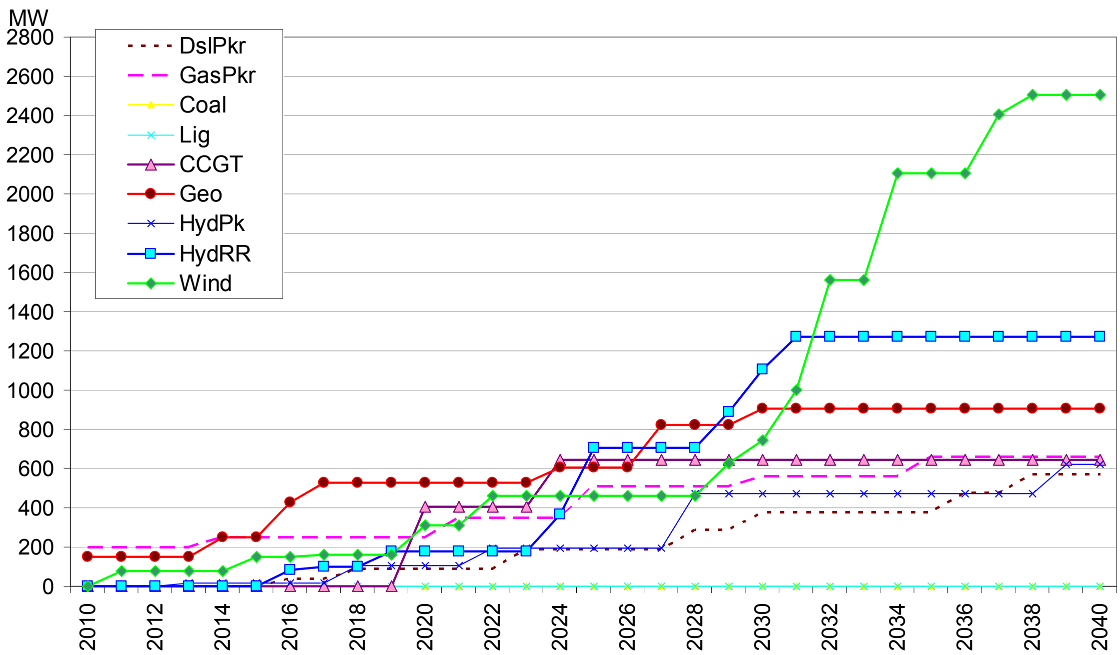


Figure 4 Gas consumption by thermal generation plant (existing and new builds)

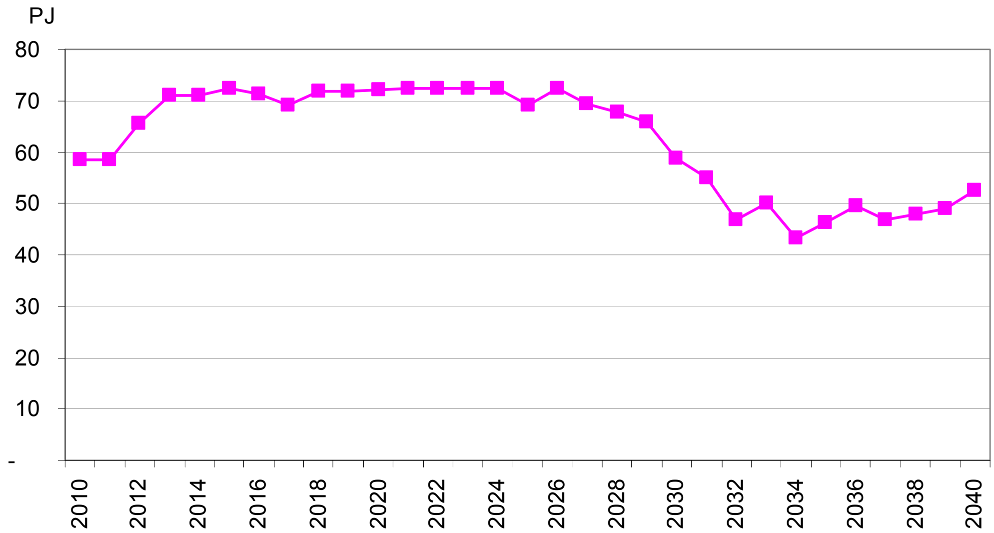
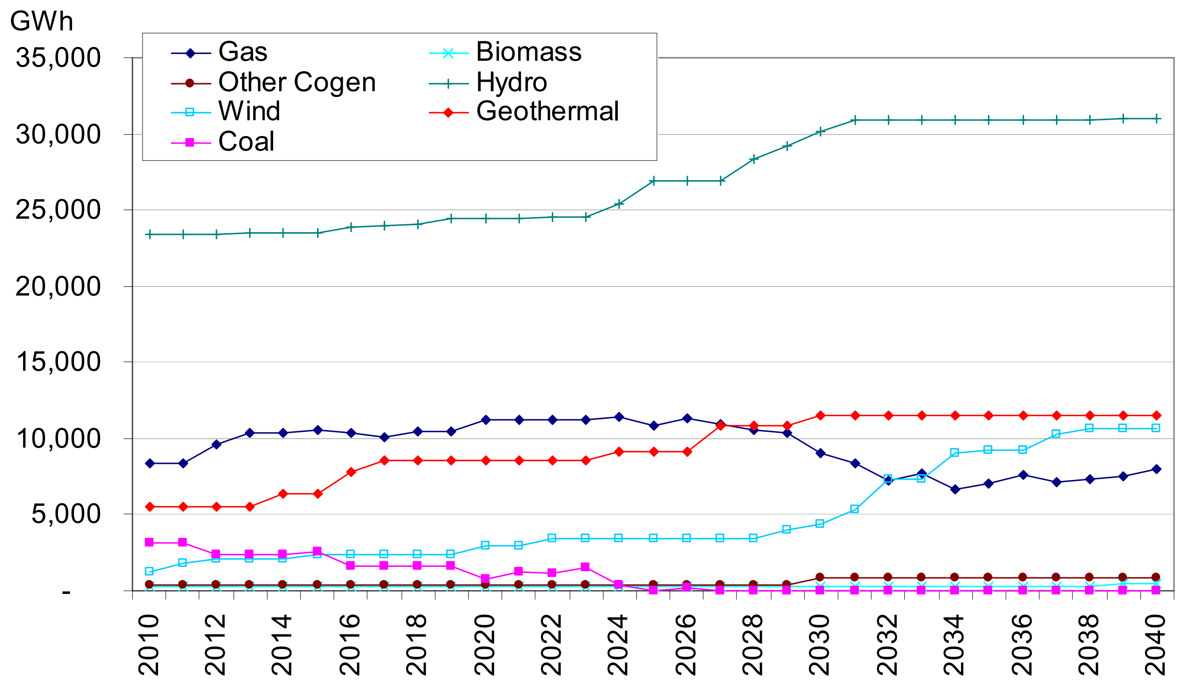


Figure 5 Generation by plant type (GWh, existing and new builds)



3.3 Electricity price forecast

3.3.1 Background

The price forecast for 2009 Outlook, which was reviewed by Energy Link[6], was based on an LP (linear program) optimisation which resulted in a time consuming process for running and converging the GEM and SADEM outputs. In the 2010 Outlook we have changed the methodology to a simpler "deterministic" model which speeds up the process considerably. The underlying intention for each type of model is identical: to obtain a wholesale price forecast which reflects the LRMC of new generation built. A comparison of the outputs from the two different models (when "reforecasting" the 2009 Outlook using the new model) showed that the two models produced consistent future price trends.

3.3.2 Overview

The excel workbook which contains the GEM assumptions has been modified by MED so that it also calculates:

- the Long Run Marginal Cost (LRMC) of each new plant built;
- the annual wholesale market price that would be required in order for all new plant to earn their LRMC over time.

A discounted cashflow model is used to calculate the Net Present Value (NPV) of a new generation investment. The LRMC is the $/MWh that a new investment must earn, on average, so that the NPV equals zero. A discount rate of 8% (post tax, real) is used to discount the cashflows[7].

The LRMC for each new plant is then used in another set of calculations which estimate the wholesale price forecast required. This set of calculations can be called the "Electricity price forecast model" (EPF model).

The intention of the EPF algorithm is to reflect, to some degree, how changes in the relative quantities and costs of the different technologies may affect the level and shape of future prices. In order to do this, the EPF model breaks the market down into 4 load blocks[8]

1a. High peak = top 2.5% of demand curve (when diesel peakers are running);

1b. Normal peak = next highest 27.5% of demand curve (when gas peakers are running);

2. Baseload = middle 60% of demand curve (when baseload plant are running);

3. Oversupply = lowest 10% of demand curve (when hydro or wind needs to be spilled).

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[6] http://www.med.govt.nz/templates/MultipageDocumentTOC____44669.aspx.

[7] An LRMC tool is also available on the MED website (http://www.med.govt.nz/templates/MultipageDocumentTOC____41972.aspx.) which can be used to compare the LRMC's of different technologies under varying assumptions such as exchange rates, fuel costs, etc. Refer to appendices for an example LRMC chart.

[8] Imagine the half hourly demand data for a year ordered from high to low to get a cumulative distribution curve. The load blocks break up the curve into manageable chunks that approximately represent typical demand patterns (ie. peak, shoulder, baseload and off-peak periods)

It is assumed that in the future, the generators who are setting the market price in each load block would want to ensure that, over time, they are covering the LRMC of their investments. This gives us the following set of rules for the EPF model:

- diesel peaker LRMC determines the price forecast for block 1a;
- gas peaker LRMC determines the price forecast for block 1b;
- higher of wind/hydro/geo/CCGT LRMC determines the forecast for block 2; and
- no-one sets the price during the oversupply block (we assume a very low price of $10/MWh).

This is a very simple set of rules designed to reflect a very complex market. In reality, wind, geothermal and run-of-river hydro will be offered into the spot market at $0.01 so cannot really "set the price" in block 2. However, investors are unlikely to build these forms of generation unless they anticipate prices at or above LRMC when their plant is running in the future. If prices do not meet LRMC then future investment will be delayed, resulting in a supply short-fall if demand keeps rising. This will eventually drive up wholesale prices (as more expensive thermal generation would be need to be dispatched) and as prices rise towards LRMC then these new plant will be built.

3.3.3 Method

The first step is to calculate a weighted average LRMC of all the relevant plant that have been built.

(1) $LRMC_{t,y} = \Sigma(LRMC_{t,p,y} * MW_{t,p,y}) / \Sigma(MW_{t,p,y})$

Subject to: $Build\_year_p <= y$

Where t = technology (diesel peaker / hydro / etc)

p = plant name, and

y = year.

An alternative to taking a weighted average would have been the maximum LRMC across the set of plant. However a maximum is too susceptible to outliers if, for example, a very small plant is built with a very high LRMC.

This gives us the following equation (2) for determining the price in block 1a:

(2) $Price\_1a_y = LRMC_{diesel,\ y}$

When calculating the prices for the remaining load blocks we also need to consider how often the relevant plant is dispatched in the other load blocks and the prices that they will receive in those other load blocks. For example, the gas peakers setting the price in load block 1b will also be running during load block 1a when the diesel peakers are setting the price. So we get the following equation (3) for determining the average price received by a gas peaker:

(3) $Weighted\_avg\_price_{gas\_pkr,\ y} = Price\_1a_y * 0.025/0.3 + Price\_1b_y * 0.275/0.3$

2.5% is the size of load block 1a, 27.5% is the size of block 1b, and 30% is the assumed capacity factor for gas peakers. Since we assume that $Weighted\_avg\_price_{gas\_pkr,\ y} = LRMC_{gas\_pkr,\ y}$, we can substitute and re-arrange the previous equation to get the following equation (4) for determining the price for block 1b:

(4) $Price\_1b_y = (LRMC_{gas\_pkr,y} - 0.025/0.3 * Price\_1a_y) * 0.3/0.275$

Note the hierarchy which prevents the reverse from occurring. The diesel peakers have the highest LRMC and so will be the last plant dispatched in the "merit order". They will only be dispatched in load block 1a and so prices in other load blocks are irrelevant (this also means that the assumed capacity factor for new diesel peakers is 2.5%).

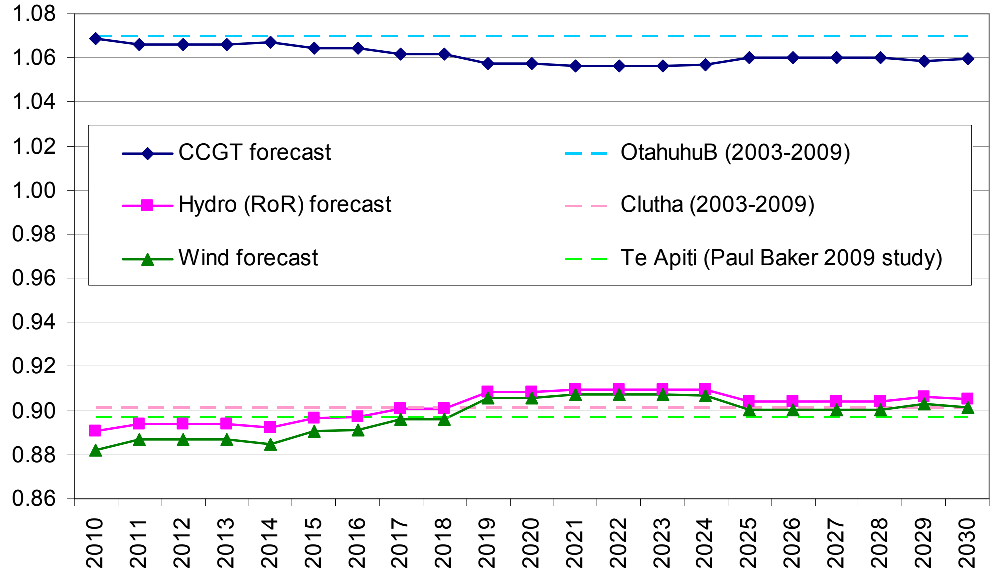
The equations for block 2 are a little more complex since there are alternative baseload technologies and more load blocks to consider. *Table 4* shows the assumed capacity factors in each load block. All of the baseload technologies (coal, CCGT, geothermal, hydro and wind) are dispatched to a varying degree in each load block. The baseload technologies with a little more flexibility (CCGT, coal, stored hydro) are more weighted towards the peakier load blocks, while the technologies with less flexibility (wind and run of river hydro) are more weighted towards the lower priced load blocks).

Table 4 Average capacity factors by load block

Block	1a	1b	2	3	All periods
Size of block	*2.50%*	*27.50%*	*60%*	*10.0%*	*100.00%*
Diesel Peaker	100%	NA	NA	NA	2.5%
Gas Peaker	100%	100%	NA	NA	30.0%
Coal	90%	90%	80%	50%	80.0%
CCGT	90%	90%	80%	50%	80.0%
Geothermal	90%	90%	90%	90%	90.0%
Hydro with storage	80%	80%	40%	20%	50.0%
Hydro run of river	40%	40%	50%	80%	50.0%
Wind	30%	30%	40%	60%	39.0%

A check of the capacity factor assumptions was performed by comparing historical generation weighted average prices (GWAP) to time weighted average prices (TWAP). The historical GWAP/TWAP ratio for the key technologies was then compared to the forecast (refer to following chart). These ratios will change over time but this is still a good "sense" check of the model assumptions.

Figure 6 GWAP/TWAP ratios



The price required for each technology (t) in block 2 looks like this:

(5) $Price\_2_{t,y} = \{ LRMC_{t,y} * \Sigma(Block_i * CF_{t,i}) - Block_{1a} * CF_{t,1a} * Price\_1a_y - Block_{1b} * CF_{t,1b} * Price\_1b_y$

$- Block_3 * CF_{t,3} * Price\_3_y \} / (Block_2 * CF_{t,2})$

Where: $Block_i$ is the (percent) size of load block number i,

$CF_{t,i}$ is the capacity factor for technology t in block i (as defined in *Table 4*), and

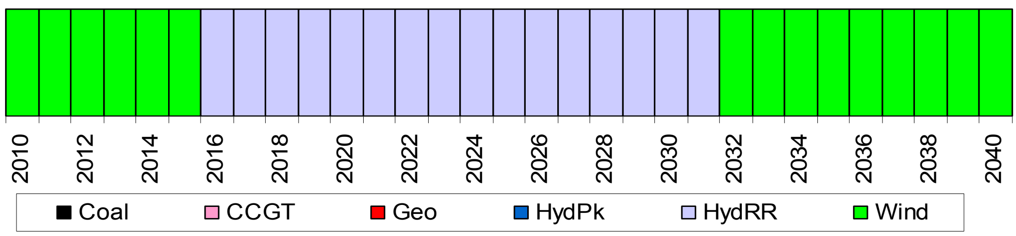
$Price\_3_y$ = \$10 (a constant).

The workings have not been shown so the interested reader can verify the algebra for themselves. The above equation gives us the price required for each technology. In order to obtain the overall price required in block 2 we take the maximum value from across the different technologies:

(6) $Price\_2_y = Max(Price\_2_{t,y})$

Figure 7 shows which technologies are setting the price in Block 2 for the Reference Scenario (ie. which technologies have the highest required price – in this case wind and hydro).

Figure 7 Technology setting the price in block 2 (2010 Reference Scenario)



These prices in block 2 are also tending to drive the overall price level. The prices in block 1a and 1b affect the volatility (or standard deviation) of prices but it is the prices in block 2 which drive the overall level of prices (since higher prices in blocks 1a and 1b will mean that block 2 prices can be lower, so long as the baseload technology is meeting its LRMC when taking the weighted average). The final price forecast quoted in the 2010 Outlook is just a weighted average of the prices in each block

(7) $Price\_final_y = \Sigma(Block_i * Price\_i_y)$

Figure 8 Price forecast by load block (2010 Reference Scenario)

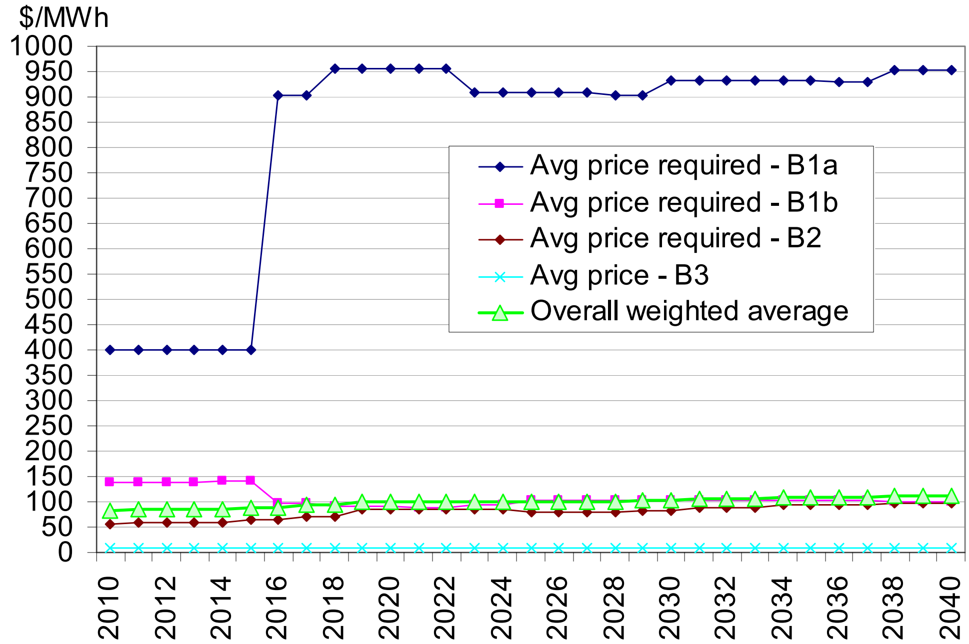


Figure 9 Price forecast by load block (1b, 2 and weighted average only)

Since the price forecasts are based on the LRMCs of new stations built, some readers may be curious how we get prices in 2010 before there has been any new build for some technologies (for example, the first diesel peaker is not built until 2016). We have default LRMC values for each technology. The default values for each technology are used in the above equations in case there are no new builds up to that particular year[9]. The default LRMC values for baseload plant all sit around $70/MWh. The values were set so that the starting 2010 price forecast was near the current wholesale price level of around $80/MWh (because of the LWAP/TWAP ratios for wind and hydro the LRMC needs to be lower).

[9] If, in the equation $\Sigma(LRMC_{t,p,y} * MW_{t,p,y}) / \Sigma(MW_{t,p,y})$, there are no new builds for technology t, up to year y, then there will still be a default plant with an LRMC (ie. p = default).

4 Gas supply and prices

4.1 Background

In 2009, MED commissioned the following reports to provide information about the potential size of the national petroleum resource, as well as to assess the competitiveness and effectiveness of the current royalty approach:

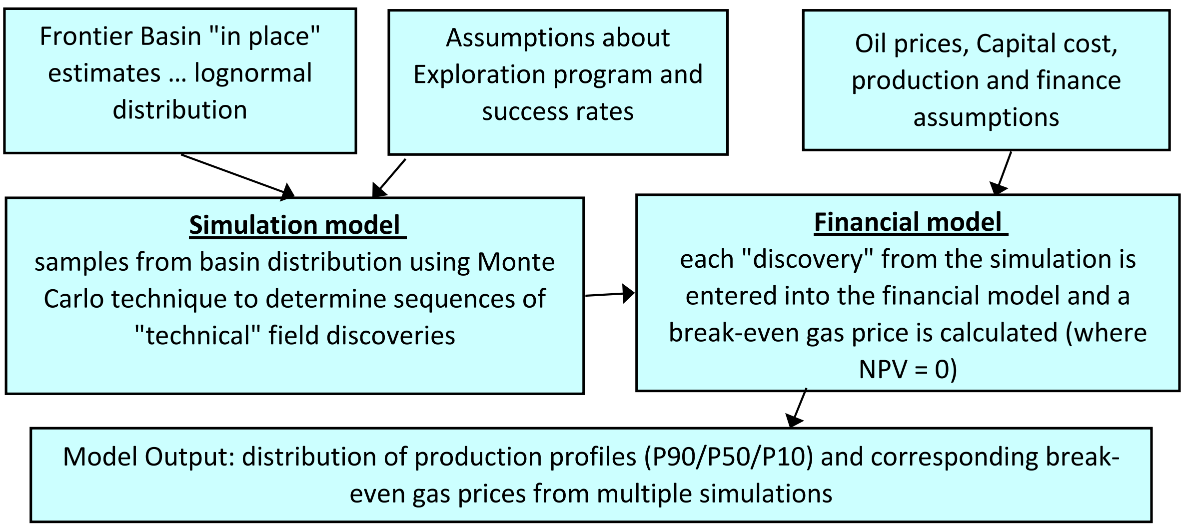
- Production and Cost Estimates for New Zealand's Petroleum Resources – Mike Adams Reservoir Engineering 2009[10]
- Potential Undiscovered Oil and Gas Resources of New Zealand - GNS Science 2009[11]
- Evaluation of the Petroleum Tax and Licensing Regime of New Zealand – AUPEC 2009[12]

Submissions were received by the industry on these commissioned reports and subsequently the capital cost and technical "in-place" resource estimates were reviewed and updated. These new estimates have been incorporated into the modelling work discussed below.

4.2 Overview of modelling process

The Energy Information and Modelling Group from the Energy and Communications Branch MED has developed a ***simulation model*** to assess New Zealand's potential undiscovered technical petroleum (oil and gas) resource and a ***financial model*** to calculate the commercial viability of the technical resource.

Figure 10 Overview of modelling process



[10] http://www.med.govt.nz/upload/70847/Michael-Adams-Reservoir-Engineering-July-2009.PDF

[11] http://www.med.govt.nz/upload/70843/Potential-Undiscovered-Oil-GNS-Science.pdf

[12] http://www.med.govt.nz/upload/70849/AUPEC-July-2009.pdf

4.3 Simulation model

The first step in the modelling process is to estimate, for each frontier basin, the technical Oil Initially in Place (**OIIP**) and technical Gas Initially in Place (**GIIP**) for the entire basin. The GNS report provides OIIP and GIIP assumptions, with the uncertainty in the estimates reflected by assuming a *lognormal* distribution. *Table 5* shows the basin OIIP and GIIP estimates at the P90, P50 and P10 levels, as well as the truncated minimum and maximum values.

Table 5 Technical in place resource estimates

	Taranaki Onshore	Taranaki Offshore	Canterbury	GSB near	GSB Far	Northland	Taranaki Deepwater	Raukumara
GIIP (tcf)								
Min	0.34	0.86	0.16	0.14	0.43	0.46	0.79	0.13
90%	0.69	1.63	0.58	0.35	1.50	1.13	2.13	0.50
50%	1.61	3.55	2.68	1.11	6.87	3.42	7.10	2.58
10%	3.75	7.75	12.50	3.50	31.50	10.38	23.75	13.33
Max	7.49	14.65	43.85	8.95	108.97	25.66	63.53	50.84
OIIP (mmbbl)								
Min	29.0	106.0	124.0	69.0	105.0	63.0	93.0	48.0
90%	63.0	238.0	275.0	150.0	250.0	144.0	263.0	150.0
50%	158.0	638.0	732.0	387.0	725.0	398.0	942.0	612.0
10%	400.0	1713.0	1950.0	1000.0	2100.0	1100.0	3375.0	2500.0
Max	852.0	3831.0	4333.0	2167.0	5000.0	2521.0	9551.0	7870.0

The simulation model samples from these basin distributions using a Monte Carlo technique. The sampling process is run several hundred times, with each sample referred to as an "iteration". Each iteration is a hypothetical future in which NZ has a certain quantity of petroleum resources.

The next step in the modelling process is to determine the likely size and number of gas and oil fields that are contained within each basin. It is assumed that the distribution of fields follows "Zipf's law", where the second largest field is half the size of the largest field, the third largest field is one third of the largest, and so on. Once the basin size and the largest field size are known, then the remaining field sizes can be calculated. *Table 6* below shows the largest field assumptions for each basin and for each basin probability level.

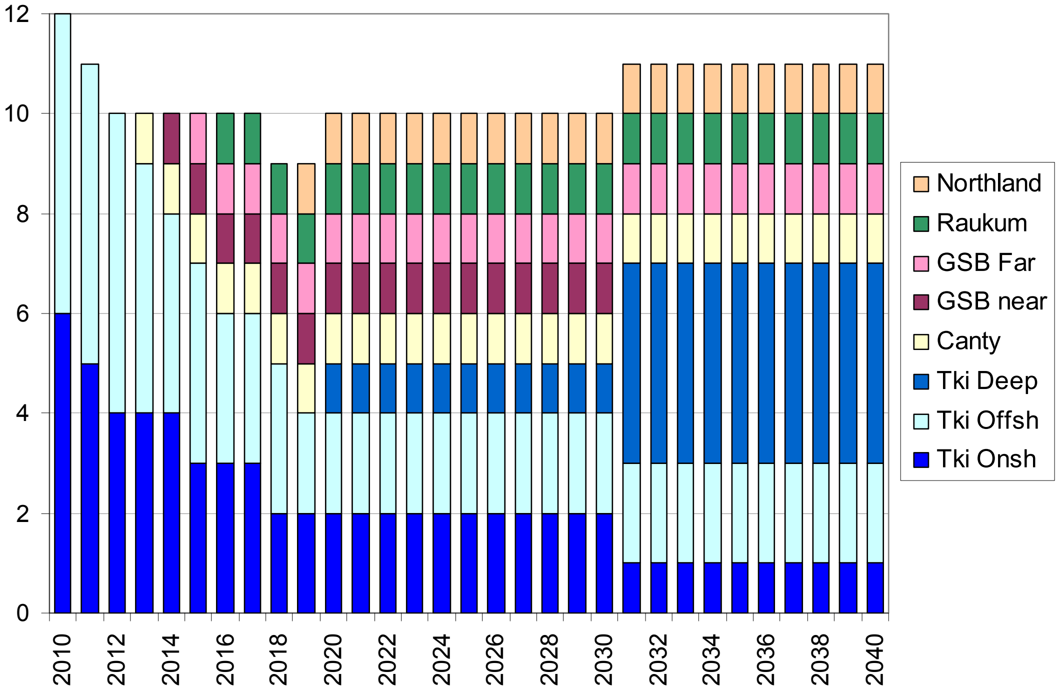
Table 6 Maximum field size for each probability level

	Taranaki Onshore	Taranaki Offshore	Canterbury	GSB near	GSB Far	Northland	Taranaki Deepwater	Raukumara
Max gas field size (tcf)								
Min	0.12	0.50	0.10	0.10	0.35	0.38	0.60	0.10
90%	0.22	0.75	0.35	0.25	1.00	0.75	1.50	0.35
50%	0.42	1.50	1.50	0.75	4.50	1.50	3.00	1.50
10%	0.86	2.50	4.13	1.75	12.00	3.38	7.00	5.25
Max	1.50	4.25	10.88	3.50	30.00	7.13	15.50	14.25
Max oil field size (mmbbl)								
Min	12.0	75.0	70.0	37.5	90.0	50.0	62.0	40.0
90%	20.0	100.0	140.0	112.5	135.0	93.0	124.0	90.0
50%	42.0	225.0	280.0	187.5	270.0	155.0	310.0	270.0
10%	90.0	475.0	560.0	337.5	630.0	341.0	837.0	720.0
Max	166.0	900.0	1050.0	637.5	1260.0	682.0	1984.0	1800.0

The next step is to determine (for each iteration) how many of these potential fields will be discovered and when they will be discovered. This requires hypothetical exploration wells to be drilled and assumptions made regarding the success of the wells. *Figure 11* and *Table 7* outline the exploration and success rate assumptions.

The exploration assumptions used in 2010 Outlook reflect a “low case” trajectory. With a rising oil price in the future, there is an expectation that exploration activity would also increase, so two alternative “mid case” and “high case” exploration paths were also modelled. However, a more conservative path was chosen for the Outlook forecasts given the uncertainty around many of the other key assumptions.

Figure 11 Exploration wells drilled each year



The probability of success for each of the basins is shown in *Table 7*. The probability of a *technical* success is assumed lower for frontier basins when compared to the established Taranaki region[13]. The probability rates are based on historical well success rates in Taranaki. They were discussed and agreed on in consultation with Michael Adams.

Table 7 Probability of a technical success

	Taranaki Onshore	Taranaki Offshore	Canterbury	GSB near	GSB Far	Northland	Taranaki Deepwater	Raukumara
Success rate (for finding oil or gas)	40%	20%	15%	15%	15%	15%	10%	10%
Probability of gas (if there is a success)	50%	48%	65%	67%	67%	48%	50%	50%

The model randomly selects a number between 0 and 100 when an exploration well is drilled. If the random number is less than the assumed success rate then the well is a success, otherwise it is a failure. For example, a random number of 17 in Offshore Taranaki is deemed a success. If there is a technical success, the model then selects another random number to determine

[13] However, the model does allow the technical success rates to slowly increase in the frontier basins if there is a successful discovery (in a given iteration).

whether the discovery is primarily oil or gas prone. Another random number is then generated to determine what sized field is discovered (ie. is it the largest, forth largest, smallest, etc)[14].

The random numbers are generated for each hypothetical exploration well drilled. This results in a sequence of discoveries and failures for each single model iteration. These technical successes and failures are stored for each iteration in a database, which contains the following information:

- Technical field size (tcf gas or mmbbl oil) by basin
- Discovery year
- Number of exploration well failures

4.4 Financial model method

The commercial viability of each technical discovery was assessed using the *financial* model. The financial model is a discounted cashflow model, which includes all the relevant income and costs an oil company would expect in the course of exploring, developing, and operating an oil or gas field.

Every gas field discovered and stored in the database is fed into the financial model and a break even gas price and production profile calculated. The break even gas price is the average price required in order for the project to attain an NPV of zero. Note that gas prone fields also produce some oil condensate which is sold at a given price (refer to Financial Model assumptions in the appendices).

Every oil field was also fed into the financial model and an NPV was calculated using an exogenous oil price assumption.

All the financial model assumptions are outlined in the appendices.

4.5 Gas model results – Reference Scenario 2010

The modelling found that between 2010 and 2050 there were, on average, around 75 oil or gas fields discovered across all of the eight basins modelled, and half of them tended to be gas prone fields. With 146 model iterations, this means there are approximately 146 x 75 ~ 11,000 individual fields stored in the database. The database was used to produce the P50 gas production/price curves and P50 oil production curves used in Outlook 2010 (the P50 results represent the 50th percentile from the data).

[14] The model assumes that the largest field will be found before the third discovery.

Figure 12 Potential P50 production profiles and break even gas prices for new discoveries (Reference scenario, prices exclude Carbon cost)

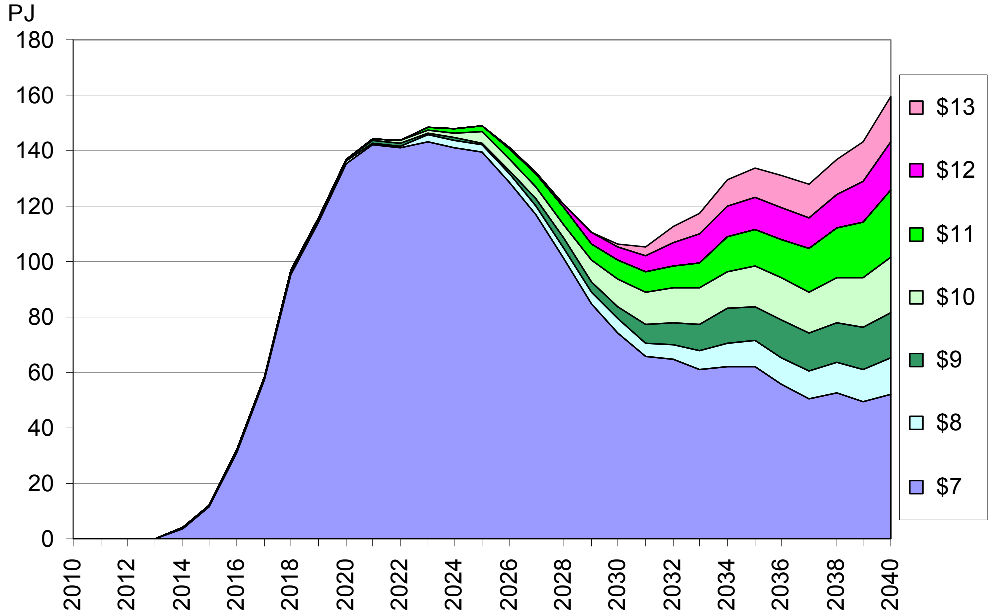


Figure 12 shows the potential P50 production volumes if all economic[15] gas fields were developed when they were discovered. The production volumes are also broken down into tranches which reflect the relevant breakeven gas prices (note that the prices exclude any Carbon cost pass through).

Figure 13 Potential P50 production from each basin (Reference scenario)

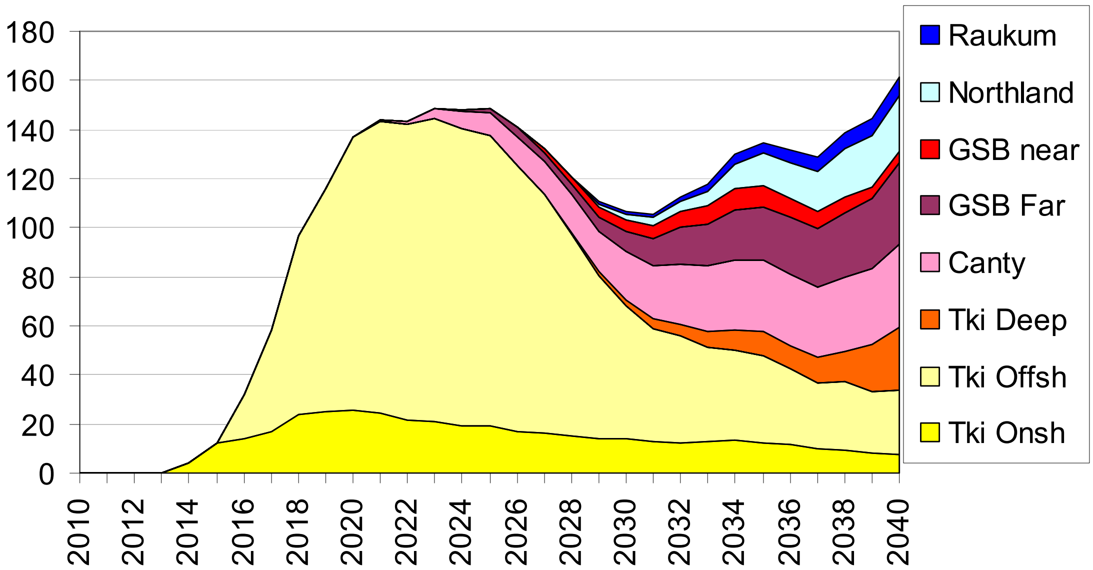


Figure 13 shows that from 2021 we could start to see some production from a frontier basin, and by 2030 around one third of the total production could come from frontier basins. Virtually all of the Offshore and Onshore Taranaki fields are in the $7 (or less) price tranche, while all the $8+

[15] A (potentially) economic gas field has been defined in this case as a field with a break even price less than $13/GJ (excl Carbon).

tranches are composed of frontier basins (refer to *Figure 29* in appendices which shows the break-even prices by basin).

Figure 14 Smoothed P50 production profiles and break even gas prices (Reference scenario, prices exclude Carbon cost)

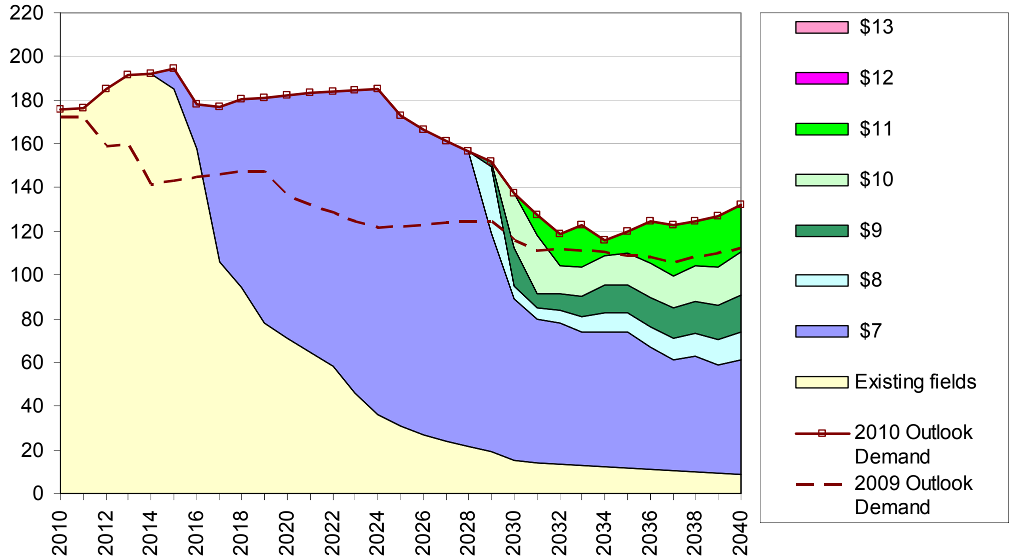
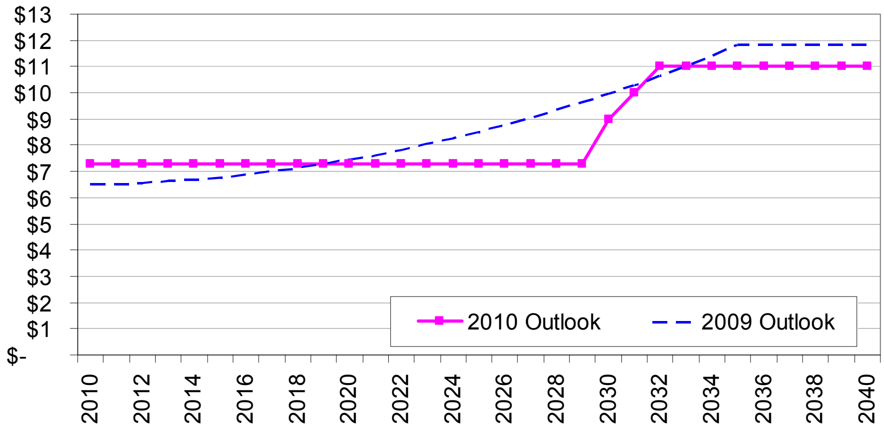


Figure 14 includes production forecasts from existing fields and then "smoothes" the production from new discoveries to match annual demand. This assumes that new gas fields are only developed when there is demand for that extra gas, and that gas storage can also be used to manage imbalances.

Figure 15 Gas price forecast excluding Carbon cost (Reference scenario)



* $50/tonne would add around $2.60/GJ

Figure 15 shows the gas price path which is determined by the supply/demand equilibrium points in *Figure 14*. The 2010 to 2029 price is actually $7.30/GJ as opposed to the breakeven price of $7. The 2009 wholesale price actual is $7.30/GJ and we assume that prices will stay at this level until a more expensive gas source is required.

4.6 Gas model results – Oil price sensitivity

Potential P50 production profiles and break even gas prices

Figure 16 High Oil Price sensitivity

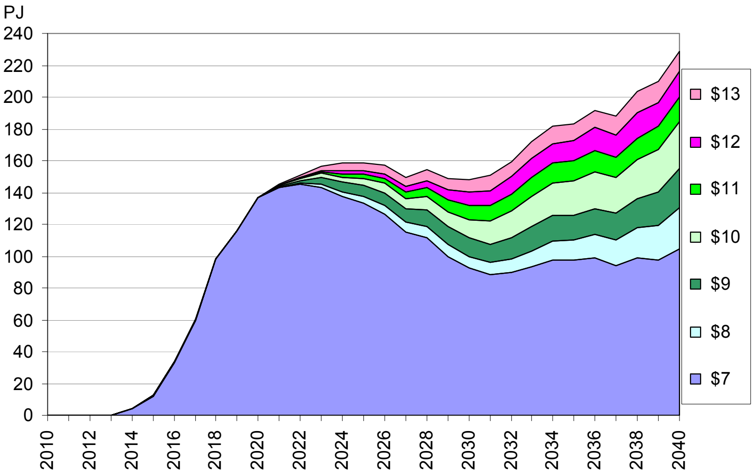
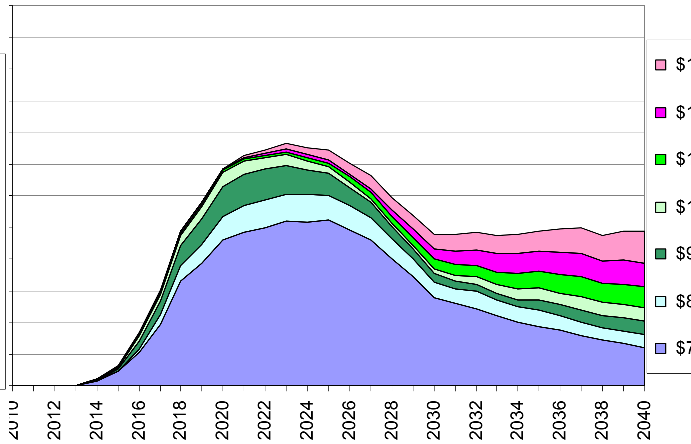


Figure 17 Low Oil Price sensitivity



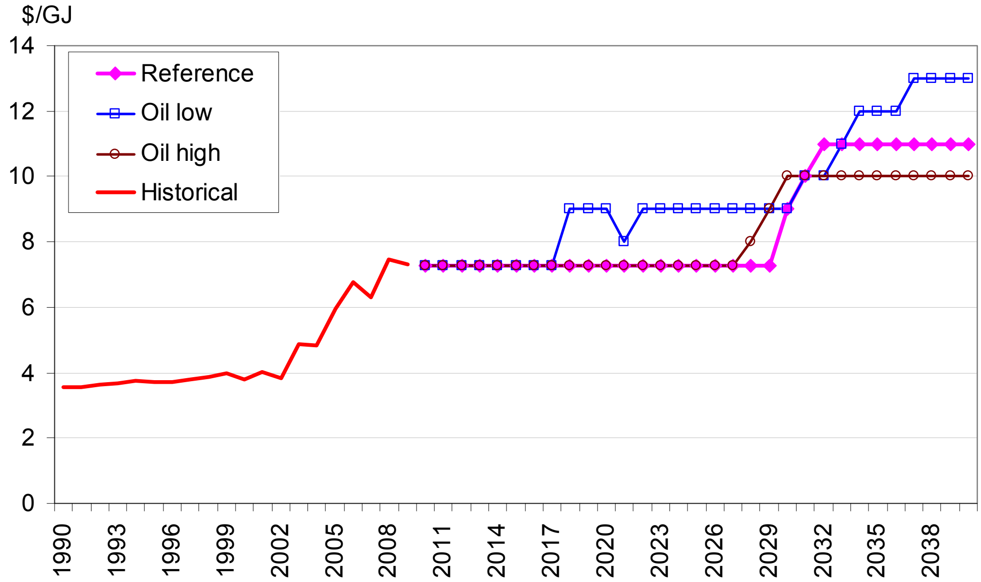
The gas supply curves were significantly affected in the low and high oil price sensitivities (see *Figure 16* and *Figure 17*). New gas fields are assumed to have oil condensate also, and so the price this condensate sells for affects the economics of gas field developments. A low oil price will result in fewer gas fields meeting commercial thresholds (or in other words, the break-even gas price increases) which results in lower potential production volumes. The inverse occurs in the high price case.

This leads to an interesting result for the gas price forecasts (*Figure 18*) with a high oil price associated with a lower long run gas price, and a low oil price leading to a higher gas price. This may seem a little odd but in a world with very high oil prices, a gas field operator may be willing to sell gas at a discount in order to extract the highly valuable oil condensate as quickly as possible. Analysis of Onshore Taranaki economics shows that some potential fields have breakeven gas prices as low as $0 because of the relatively low capital costs (compared to offshore developments) and the highly valuable oil condensate (refer to *Figure 29* in the appendices).

Note that this result only holds if the NZ gas market remains disjointed from the international gas (LNG) market. If NZ were to import or export gas then NZ's domestic gas prices would more than likely become indexed to the oil price[16].

[16] Unless we were exporting gas from a remote offshore location, far from NZ's current pipeline infrastructure, such as Great South Basin.

Figure 18 Gas price forecast excluding Carbon cost



5 Road Transport – Vehicle Fleet Model

On-road transport energy demand includes that used in the on-road movement of New Zealand's motor vehicle fleet including light private vehicles (LPV – cars and SUVs with less than 9 seating positions), light commercial vehicles (LCV – vans, utility, small trucks <3.5t), heavy commercial vehicles (HCV - trucks >3.5K), buses, and motorcycles and mopeds.

New Zealand's energy data as published in the *New Zealand Energy Data File*[17] provides time series data of the split of liquid fuels by end-use sector. Transport is the major user of petrol, diesel and total oil product consumption. However this data can provide little information as to the further split of this fuel by vehicle classes; such as between passenger transport and freight for example or the relative use by cars as compared to trucks. For modelling our future transport energy demand we require a model of this split as the various demands will likely grow at very differing rates even within our *Reference Scenario* and certainly between alternative scenarios.

Statistics and dynamics of the vehicle fleet are discussed in depth in the Ministry of Transport's annual publication *"The New Zealand Vehicle Fleet"*[18]*.* These statistics also provide much of the base data used in the Vehicle Fleet Model (VFM) – a joint MoT/MED operated model that is used to project the future vehicle fleet, its travel, fuel demand and greenhouse gas emissions. Important fleet and travel statistics that build into the model include

- Historical fleet data including vehicle numbers - by vehicle type, size, fuel, the year of manufacture, origin (new or used import).
- Annual travel data as vehicle kilometres travelled (VKT) – also split as above
- the vehicles entering the fleet each year including both new vehicles and used imports – also split as above

The VFM combines this data as

$$\text{Energy}_{\text{Transport}} = \sum_{\textit{fuels, vehicle classes \& size, road type and condition}} \text{VKT}_{\text{average}} \times \text{vehicles} \times \text{fuel factors}$$

[17] www.med.govt.nz/energy/edf

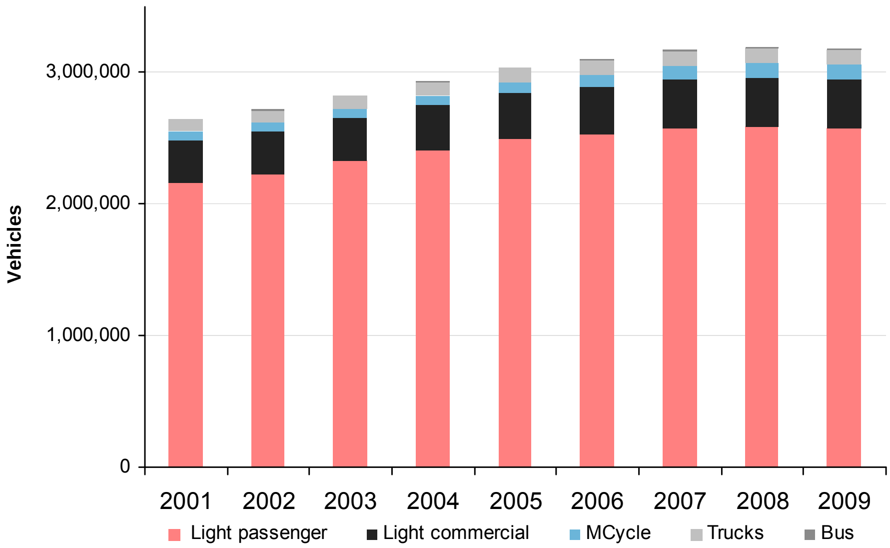
[18] www.transport.govt.nz/research/newzealandvehiclefleetstatistics/

5.1 Travel, fleet and fuel – historical data

5.1.1 Vehicle data

Figure 19 shows vehicle numbers for years from 2000; 2009 being notable for the first ever decline in light vehicle numbers. Despite this drop, New Zealand, with over 3 million vehicles, has one if the highest per capita vehicle ownership rates in the world at close to 700 vehicles per 1000 people.

Figure 19 New Zealand vehicle fleet

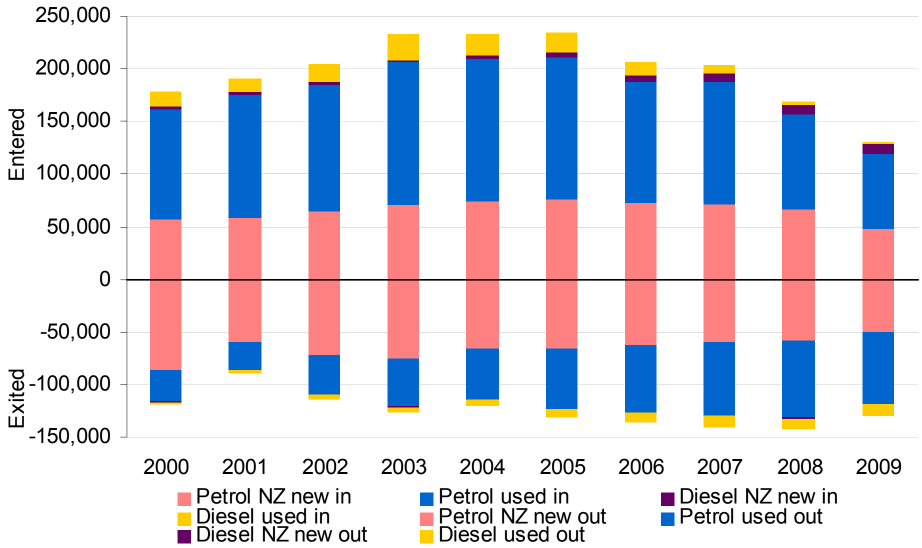


Source: Ministry of Transport[19]

Also of importance when projecting the future vehicle fleet is the rate that new and used imported vehicles enter and leave the fleet and the mix of these vehicles. The following figure shows that in the most recent years the rate of vehicle purchase has slowed while the vehicles leaving the fleet has remained more stable. These two factors combined result in the flattening of the total fleet – even prior to 2009's unusually low levels.

[19] www.transport.govt.nz/research/newzealandvehiclefleetstatistics/

Figure 20 Vehicles entering and leaving the fleet

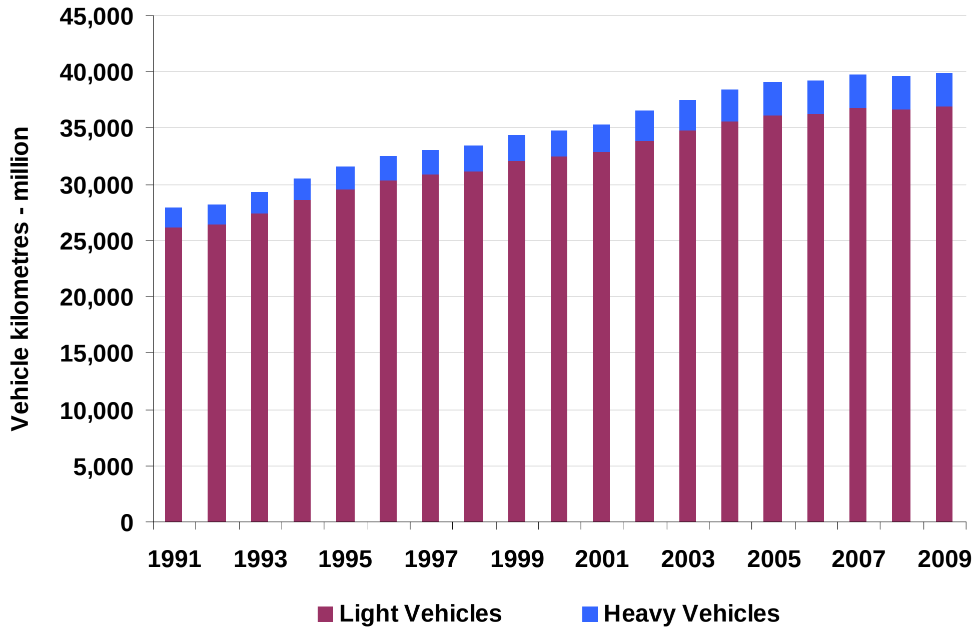


The VFM projects the future rate of new and used imports entering the fleet and expects a return towards long run average levels as GDP growth returns to the economy.

5.1.2 Travel data

Estimates of the average travel by vehicle are made from information gathered through the vehicle warrant/certificate of fitness process (WoF/CoF) which records odometer readings from vehicles. This allows estimates of the average travel per year by vehicle type, vehicle age (year of manufacture), fuel (petrol, diesel, and electric) and size (light vehicles by engine-cc band, heavy vehicles by gross vehicle mass class). Cross multiplying these averages by vehicle numbers gives an estimate of travel by each vehicle class and in total. *Figure 21* shows that light vehicles dominate VKT although the travel of the heavy fleet has grown strongly.

Figure 21 Vehicle Kilometres Travelled (VKT)



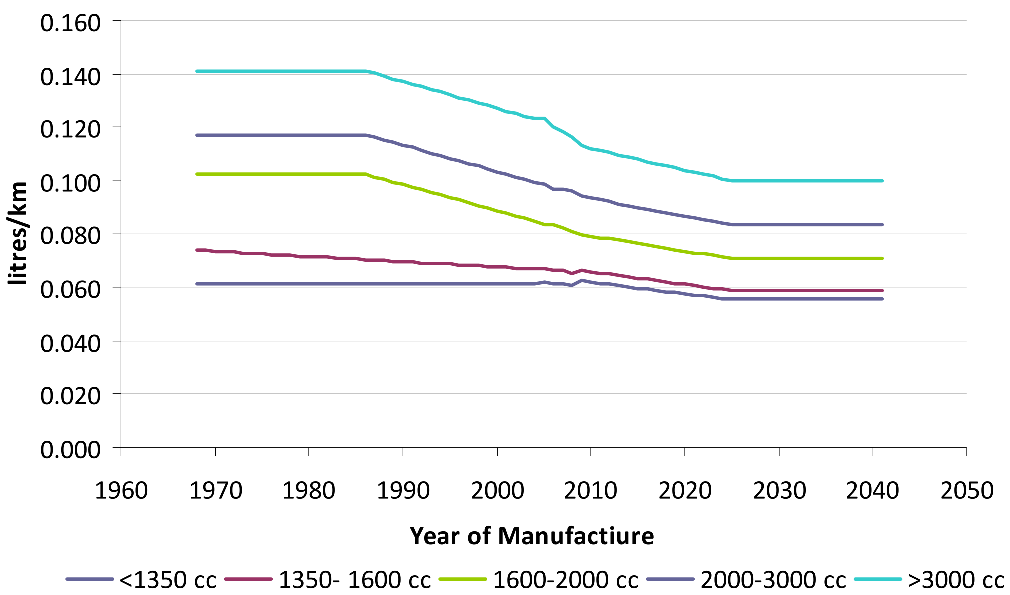
Further information on this travel is gained from on-road traffic surveys which allow for estimates to be made of where this travel occurs in terms of road type (urban, rural, highway) and traffic condition (congested, interrupted, free running and motorway). Also assumptions are made as to the ratio of travel made with the vehicle in “cold start” condition. This split of VKT by road type and traffic condition is important for modelling fuel factors which can vary greatly over the range of conditions.

5.1.3 Fuel factors

While our energy statistics give us total by fuel we are unable to authoritatively split this fuel between vehicle classes. This step is needed if we are to be able to model a range of future scenarios where the various vehicle classes are free to grow at different rates. Thus our modelling requires information on likely fuel factors (litres per km) by vehicle type.

The vehicle registration process in New Zealand now records test cycle fuel factors for light vehicles and these are now used to estimate the fuel use factors for this group of vehicles. *Figure 22* below shows our modelled fuel factors – with factors being both back-cast and forecast from the factors recorded in the 2006 -2009 period.

Figure 22 Light Petrol Vehicle fuel factors - by engine size class



The projected factors include an efficiency improvement within each class of 0.75% per year to 2025 from when we assume all efficiency gains have been made. This cumulative improvement of 11% over 15 years is conservative in that it is much lower than what has been achieved in Europe over recent years where a higher rate of improvement has been legislated. However there is no guarantee that the most efficient vehicles will be popular here as they will often be sold here at a premium price (as has been seen with some hybrid models)

In using these modelled fuel factors we are making a set of further assumptions. In particular, there is a leap from test cycle fuel economy to real world driving – however as we have information on the VKT split by road and traffic condition we are able to attempt to adjust for some of the difference between the test cycle and New Zealand’s average driving experience. Other factors such as driving style, hills, road surface etc are beyond our ability to capture.

Similarly, fuel factors are derived for light private diesel vehicles and also light commercial vehicles. There is little publicly available data on fuel use factors for the heavy fleet with these known to vary greatly by loading factor and drive cycle. The factors used are on average around 3 times greater than for the light fleet and this means that the heavy fleet accounts for a much greater share of fuel demand than its share of VKT or vehicles.

Finally, within the historical period, we are able to re-calibrate all fuel factors by comparing the total fuel modelled to that reported in the energy statistics. Modelling improvements made in recent years have seen a closer agreement being reached between modelled and reported on-road transport fuel demand.

5.2 Vehicle Fleet Modelling (VFM)

Utilising the historical data discussed in the previous section, the VFM then models relationships which are used to provide the core projections of travel (VKT) and the future vehicle fleets, for the projection period 2010 to 2030. Further discussion of the models is included in the following sections.

5.2.1 Travel Demand Projection

Travel demand

Light Fleet

$$VKT_{year} = population_{year} * VKT/capita_{year}$$

where,

$$VKT/\ capita_{year} \sim f\ (GDP/capita_{year},\ fuel\ price_{year},\ vehicle\ price_{year},\ Saturation\ level,\ historical\ data)$$

Heavy Fleet

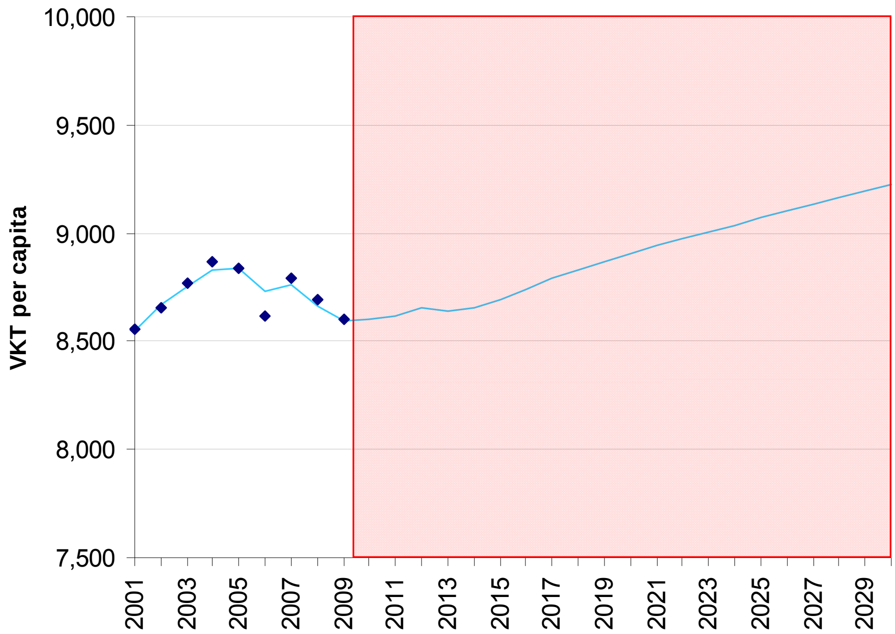
$$VKT_{year} \sim f\ (GDP_{year},\ fuel\ price_{year},\ historical\ data)$$

The key projection made in modelling on-road transport energy demand is that of the future vehicle kilometres travelled. The approach taken for the light fleet is to model vehicle travel per capita (i.e. VKT/capita) and then project total travel by multiplying by future population projections.

Travel per capita is projected by a model of the relationship seen historically between travel (VKT) per capita and relative wealth (GDP per capita) and cost of travel (based on cost of fuel and vehicles). The model assumes that individual travel will increase along with GDP but in time will be capped by a saturation level of travel above which we will have no need or desire to travel further.

In recent years per capita travel has flattened during a time when both higher fuel prices and then the recession have both had some impact on travel growth. What is not really clear is if any of the flattening is a result of us having already reached a road travel saturation level? Similar flattening in travel demand has been observed in the US, UK and Europe and a range of influences have been suggested – including, mode switching (which in New Zealand's case may be from road to air travel in line with the strong growth in inter-city flying); some replacement of domestic travel with international travel, the effect of growing tourism, the effect of the internet encouraging home based activity, demographic changes – the list no doubt goes on.

Figure 23 Road travel VKT per capita

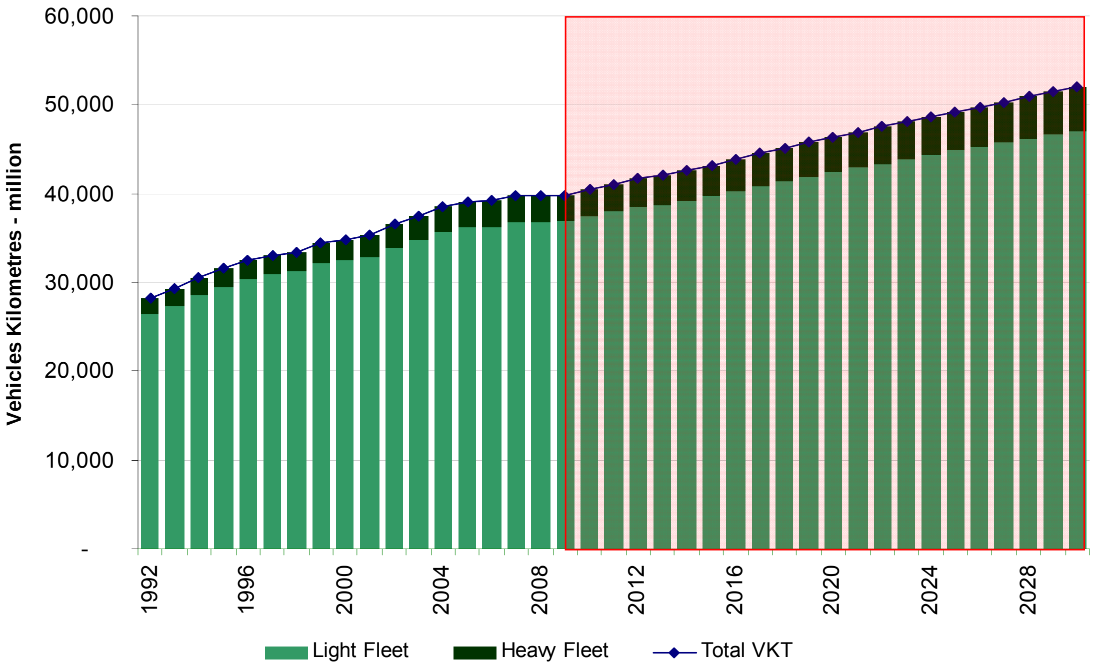


Despite this uncertainty, our model takes the assumption that this saturation level has not yet been reached and sets this at 10,000kms per capita - well above current levels. The graph shows the projection of travel per capita increasing with GDP to close to 9,250 kms per person by 2030.

Heavy truck VKT is projected by a model which considers the historical relationship of this with GDP and diesel price. GDP is the key explanatory variable with demand being found to be very inelastic to fuel price. Population is not specifically included in the model as the growth seen in HCV travel has been seen to grow independently of this in the previous decade.

Combining the projection for light and heavy fleet travel, we get

Figure 24 On-road Travel Projection 2010-2030



Heavy fleet travel grows more strongly than light travel – a product of future GDP growing at around 2% compared to population growth of ‹ 1%.

5.2.2 Fleet Size

Fleet size

Model for LPV and M/C

$$\text{Fleet size}_{year} = \text{population}_{year} * \text{vehicles per capita}_{year}$$

where, vehicles per capita $_{year}$ ~ f(year, saturation level, historical data)

Model for LCV, HCV and Buses

$$\text{Fleet size}_{year} = \text{population}_{year} * \text{vehicles per capita}_{year}$$

where,

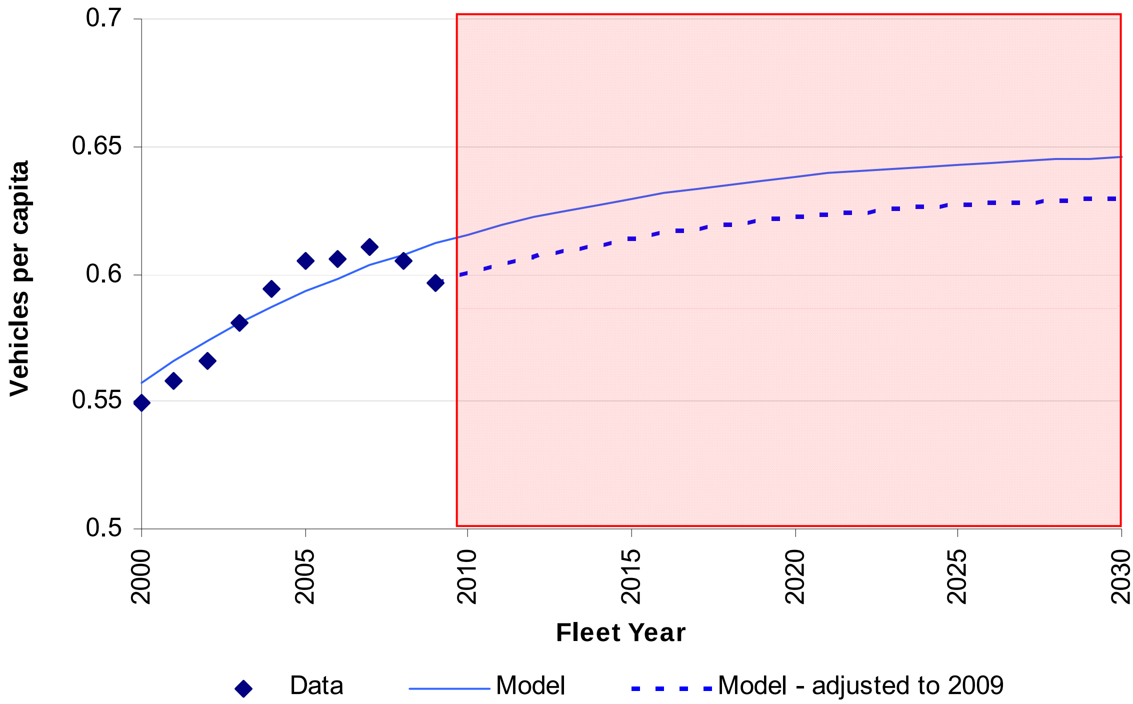
vehicles per capita $_{year}$ ~ f(year, saturation level, GDP/capita $_{year}$, historical data)

Fleet size is modelled independently of the travel model. New Zealand already has a high car ownership rate sitting third in the world rankings[20] – much above our position based on relative wealth. The reasons for the high ownership rate includes, amongst others: the affordable vehicle supply that we receive in the form of used Japanese vehicles, the low vehicle tax regime that places little penalty on owning multiple vehicles and the lack of private transport alternatives in many cities and in rural areas.

The car ownership rate had grown strongly in New Zealand throughout the 1990s and early 2000s. The assumption made in model fitting is that the rate will move closer to a "saturation level" at which no higher level of ownership is desired. This level has been assumed at 0.65 which happens to be the level already reached by Luxembourg who currently have the highest ownership rate seen in the world.

[20] http://www.economist.com/node/12714391

Figure 25 Light Private Vehicles per capita



The model fitted is

$$R(t) = S/[1+ A \exp(-t/T)].$$

R is the rate of vehicle ownership i.e. vehicles per capita. It is assumed that R increases with time to the saturation level S – assumed at 0.65. The constant T is found via a least squares fit to existing data.

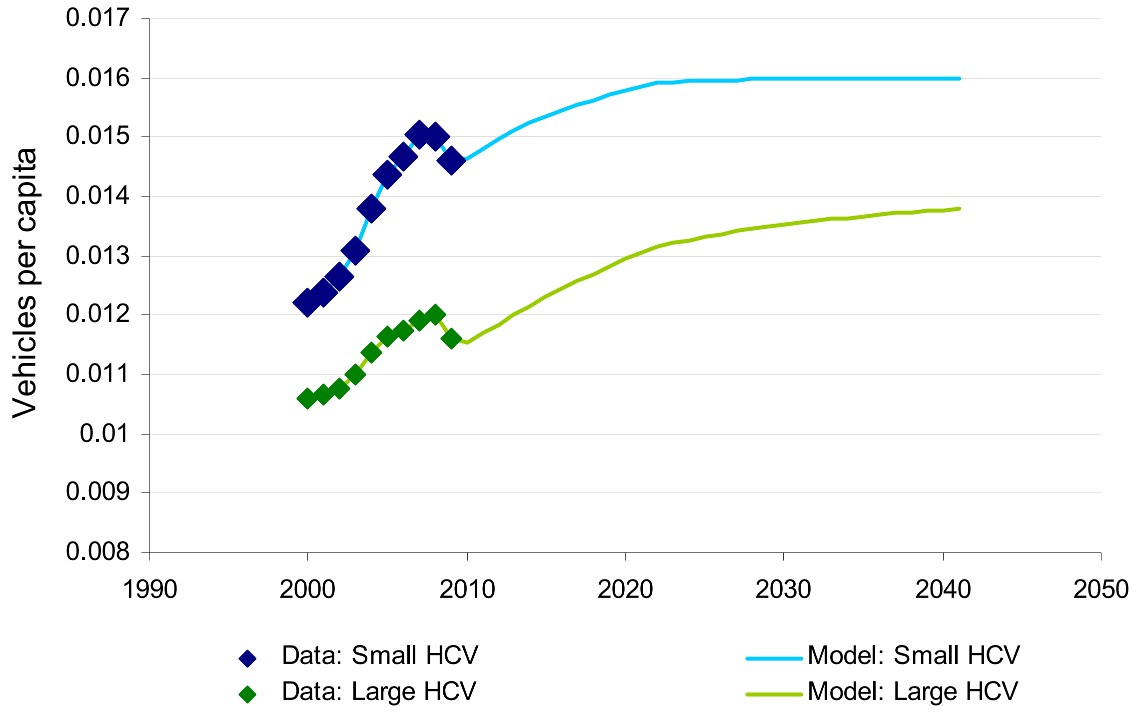
In addition we have found it necessary to adjust the model fit downward to sit on the 2009 level of ownership. The drop in per capita ownership level seen in the last two years has been unexpected and not predicted by our model form. While it is easy to point to the recession to explain this fall it may be indicating that a saturation level may have already been reached at around 600 vehicles per 1000 people. Other influences that may be impacting may include the effect of our aging population, the move to live in inner city apartments in our major cities, increases in fixed vehicle costs such as the ACC levy increases and ongoing improvements in the provision of public transport.

Similar models are fitted for LCVs and HCVs. The HCV fleet model has an additional GDP factor:

$$R(t) = S/[1+ AG^g \exp(-t/T)]$$

Where the G = the GDP/capita from the previous year, which allows for the time taken for the effect of changes in GDP to filter through the economy.

Figure 26 Heavy Commercial Vehicles per capita



5.2.3 Vehicle Uptake – New and Used Imports

New and Used Vehicles entering the fleet

LPV, LCV, HCV, Buses, M/C

$$\text{New Vehicles}_{\text{year}} \sim f\,(\text{GDP}_{\text{year}}, \text{historical data})$$

$$\text{Used Imports}_{\text{year}} \sim f\,(\text{GDP}_{\text{year}}, \text{historical data})$$

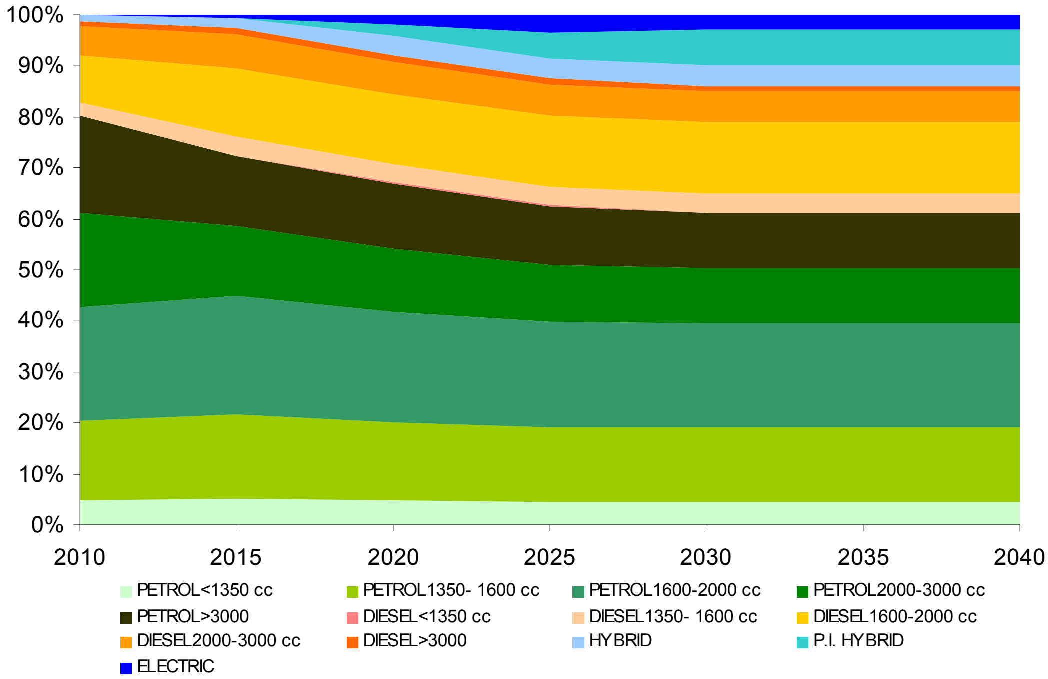
As highlighted earlier in *figure 20* vehicles enter the New Zealand fleet as both new vehicles and as used imports. Projections of future vehicle entering the fleet are made with as simple model that grows the vehicle purchase rate along with GDP growth.

5.2.4 Vehicle Uptake – Vehicle size and fuel - Market Shares

The modelling assumptions around new and used import vehicles that enter the fleet are made to line up with market shares observed in 2009 and also to pick up on some of the recent and expected trends. Assumptions made include:

Light Private Vehicles

Figure 27 New Light Private Vehicles - Market Share Assumptions



- Diesel LPVs continue their recent growth in share to hit 25% of all LPV New Vehicle sales by 2015 and remain stable from there.
- Hybrid Petrol vehicles make up 4% of LPVs by 2020.
- Electric Vehicles (EVs) and Plug-in Electric Vehicles (PHEVs) contribute 0.7% of LPVs by 2015; 4% in 2020; 8.5% in 2025 and 10% in 2030. PHEVs grow to provide 70% of these electric vehicles by 2030.
- Used import shares lag new by 5 years. There is no supply of LPV diesel vehicles available from Japan with this share replaced by petrol.

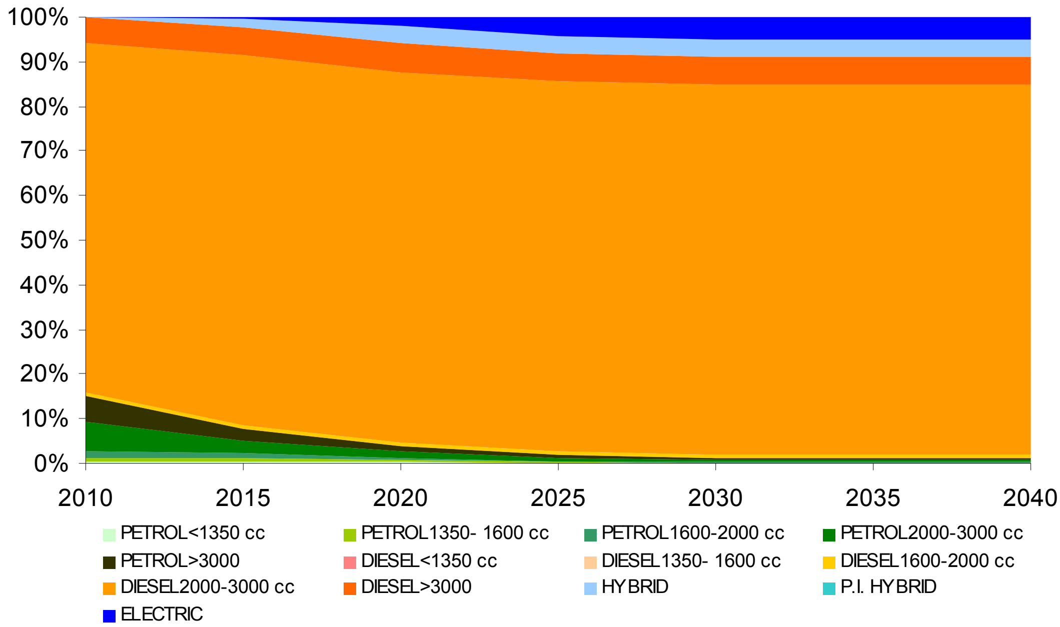
Electric vehicles are included for the first time in an Energy Outlook *Reference Scenario* – they have been included in earlier scenario studies including the *Changing Gear* scenario in *Energy Outlook 2009*.

As of December 2010 both EVs and PHEVs are being manufactured by mainstream auto-makers including General Motors, Mitsubishi and Nissan and released for sale in Europe, Japan and the USA. Some of these are already in New Zealand as part of trials being run by Mitsubishi and Toyota. Virtually all OEMs (Original Engine Manufacturers) have announced intentions to move into production of electric light vehicles building up from initial low levels to tens of thousands and beyond. With New Zealand's history of following motoring trends we can certainly expect these vehicles to sell here but at what level is very much a guess ultimately depending on market acceptance and price.

Assuming current policies New Zealand will lag the uptake rate expected in many other OECD countries where governments have established significant incentive programmes to stimulate their uptake. Our market share projections in the *Reference Scenario* are suitably conservative and in limiting 2030 share to 10% of light vehicles we maintain "business as usual" conditions with the majority of transport energy provided by oil products.

Light Commercial Vehicles

Figure 28 Light Commercial Vehicles Market Share Assumptions



- Diesel LVs continue their growth to dominate LCV vehicle sales
- Electric vehicle uptake is at half the level seen for LPV – growing to 5%.

Heavy Commercial Vehicles & Buses

- Market shares (GVM class) remain stable at those seen in 2009
- Over 98% of heavy commercial vehicles purchased operate on Diesel.

5.3 VFM – Vehicle stock turnover modelling

Armed with projections of yearly fleet totals, the number of new and used-import vehicles entering the fleet each year, the market share of these vehicles by vehicle size and a base year (2009) fleet breakdown; the model then determines detailed fleets for each year. This step effectively estimates the number and distribution (size and age) of vehicles scrapped each year that give the required fleet size.

i.e. Vehicles scrapped $_t$ = Vehicles year $_{t-1}$ + Vehicles added $_t$ – Vehicles year $_t$

The profile of scrapped vehicles is based on historical data and an assumption that the scrapping profile by vehicle age will continue.

5.4 VFM – VKT allocation to vehicles

With fleets established for all future years and VKT totals projected, the VFM then apportions total VKT over vehicles allowing for their fuel, size and age.

5.5 VFM – VKT allocation to roads

It also apportions the same VKT totals over road types and traffic conditions. The model projects future road growth and traffic conditions based on regional data on current road types, traffic conditions and the relativity between regional and national population growth.

5.6 VFM – Fuel use calculation

The last step for the VFM is to cross multiple the allocated VKT by the fuel factors. As discussed the fuel factors are scaled to reflect the impact of the road type and traffic condition on fuel consumption.

5.7 VFM – Model Outputs

Some further detail on fleet model outputs.

5.7.1 Fleet

To come.

5.7.2 Vehicle kilometres travelled

To come.

5.7.3 Energy

To come.

6 Appendices

6.1 Oil & Gas Financial model assumptions

The financial model is driven by a set of universal assumptions and a set of field specific assumptions (based on the field type, location, and size). The universal assumptions are detailed below:

- Oil price trends towards the International Energy Agency's long-term price projection (around US$120/bbl)
- Discount rate – 15%
- Exchange rate (US$/NZD$) – 0.6
- Debt financing – 60% (for income tax purposes)
- Interest – 7%
- Inflation – 2%
- Corporate tax rate – 28%
- Emissions costs – Applied to the calculated fuel flaring and own use (3% of annual production) at $25/t for Kyoto commitment period one, $50/t post Kyoto commitment period one.

Development capital expenditure was depreciated using a straight line approach (7 years) from the year it was incurred[21]. Exploration capital expenditure was accounted for as a tax deduction in the year that it occurred. Abandonment capital expenditure was carried back and spread over four years.

Five production and cost scenarios were created for each of the basins modelled for oil and gas based on the size of the field. When individual fields were discovered in the simulation, they were matched to the nearest highest and lowest scenarios, and the production and cost assumptions for the simulated field were interpolated from these two scenarios. For each of the oil and gas scenarios, the financial model included 20+ cost categories ranging from exploration seismic through to operating costs and abandonment. These costs are based on revised estimates from the Michael Adams Reservoir Engineering report.[22] The cost information is summarised in the following tables in five key categories for four different size gas fields and three different size oil fields:[23]

i. development and appraisal capital expenditure – This includes seismic, appraisal, and development well capital expenditure;
ii. infrastructure and pipeline capital expenditure[24] – This includes gas processing plants, pipelines (both local and to the North Island for South Island gas), platforms and abandonment capital expenditure;

[21] To be conservative we have assumed that the oil company has existing operations in New Zealand so the exploration and development Capital costs and tax can be offset against other projects in New Zealand.

[22] Production and Cost Estimates for New Zealand's Petroleum Resources http://www.med.govt.nz/upload/70847/Michael-Adams-Reservoir-Engineering-July-2009.PDF

[23] The modelling assumes that facilities are bought rather than leased. Where projects lease their facilities their development costs will be lower, but their operating costs will be higher, than those listed in table 4 and 5.

[24] Within the simulation of New Zealand "inc" basin development the first field builds all of the required infrastructure such as processing plant and pipeline to the North Island while the subsequent fields do not build this same infrastructure but pay higher processing costs. This is to avoid building multiple pipelines to the North Island and multiple gas processing plants within a single basin.

iii. fixed annual operating costs – Includes all fixed operating costs associated with operating specific oil or gas field;
iv. variable costs are listed individually in the tables below; and
v. other costs.
vi.

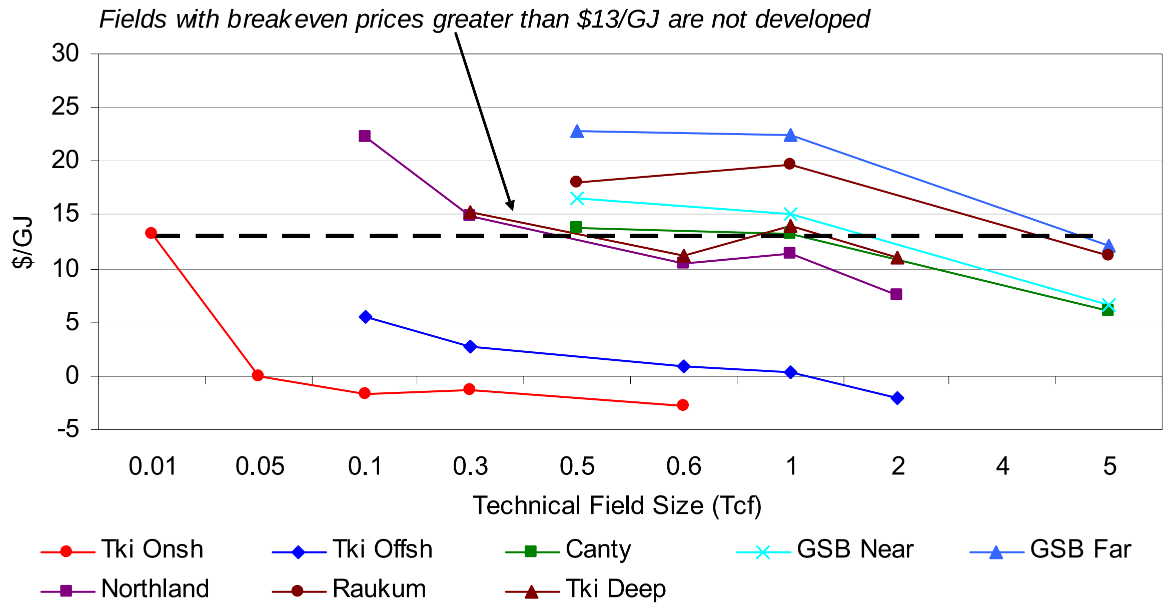
Table 8 Summary of costs - Gas (NZ$ million, real 2009)

Field size	Taranaki Onshore	Taranaki Offshore	Taranaki Deepwater	Canterbury	GSB (Near)	GSB (Far)	Northland	Raukumara
Development and appraisal well capital costs								
0.5 tcf*	213	613	763	620	620	930	763	830
1 tcf	N/A	680	1180	995	995	1430	1138	1330
5 tcf	N/A	N/A	N/A	1820	1820	2530	N/A	2430
10 tcf	N/A	N/A	3013	2645	2645	3630	N/A	3530
Platform and pipeline capital costs								
0.5 tcf*	73	292	667	975	1225	1392	500	1225
1 tcf	N/A	542	1167	1308	1558	2058	750	1892
5 tcf	N/A	N/A	N/A	2292	2542	3875	N/A	3708
10 tcf	N/A	N/A	5417	5117	5283	6950	N/A	6950
Abandonment capital costs								
0.5 tcf*	10	50	50	50	50	50	50	50
1 tcf	N/A	83	83	83	83	83	83	83
5 tcf	N/A	N/A	N/A	167	167	167	N/A	167
10 tcf	N/A	N/A	250	250	250	250	N/A	250
Fixed annual operating costs								
0.5 tcf*	35	100	100	100	100	100	100	100
1 tcf	N/A	117	117	117	117	117	117	117
5 tcf	N/A	N/A	N/A	133	133	133	N/A	133
10 tcf	N/A	N/A	150	150	150	150	N/A	150
Variable operating costs								
Gas Processing ($/GJ)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Liquids Treatment ($/bbl)	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Water Treatment ($/bbl)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Other capital costs								
Exploration	71.7	358.3	858.3	531.7	531.7	713.3	525.0	1046.7

Table 9 Summary of costs - Oil (NZ$ million, real 2009)

Field size	Taranaki Onshore	Taranaki Offshore	Taranaki Deepwater	Canterbury	GSB (Near)	GSB (Far)	Northland	Raukumara
Development and appraisal well capital costs								
100 mmbls	196	347	513	470	470	730	538	730
650 mmbls	N/A	1347	1680	1445	1445	2030	1513	2030
1000 mmbls	N/A	N/A	2097	1820	1820	2530	N/A	2530
Platform and pipeline capital costs								
100 mmbls	50	833	1000	833	833	1000	833	1167
650 mmbls	N/A	1792	2583	2225	2392	2167	2000	2975
1000 mmbls	N/A	N/A	3083	2642	2808	3308	N/A	3475
Abandonment capital costs								
100 mmbls	7	67	67	67	67	67	67	67
650 mmbls	N/A	267	267	267	267	267	267	267
1000 mmbls	N/A	N/A	333	333	333	333	N/A	333
Fixed annual operating costs								
100 mmbls	35	65	126	83	83	126	83	126
650 mmbls	N/A	115	210	155	155	210	155	210
1000 mmbls	N/A	N/A	257	155	155	257	N/A	257
Variable operating costs								
Gas Processing ($/GJ)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Liquids Treatment ($/bbl)	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Water Treatment ($/bbl)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Other capital costs								
Exploration	65	358	865	525	525	713	525	1047

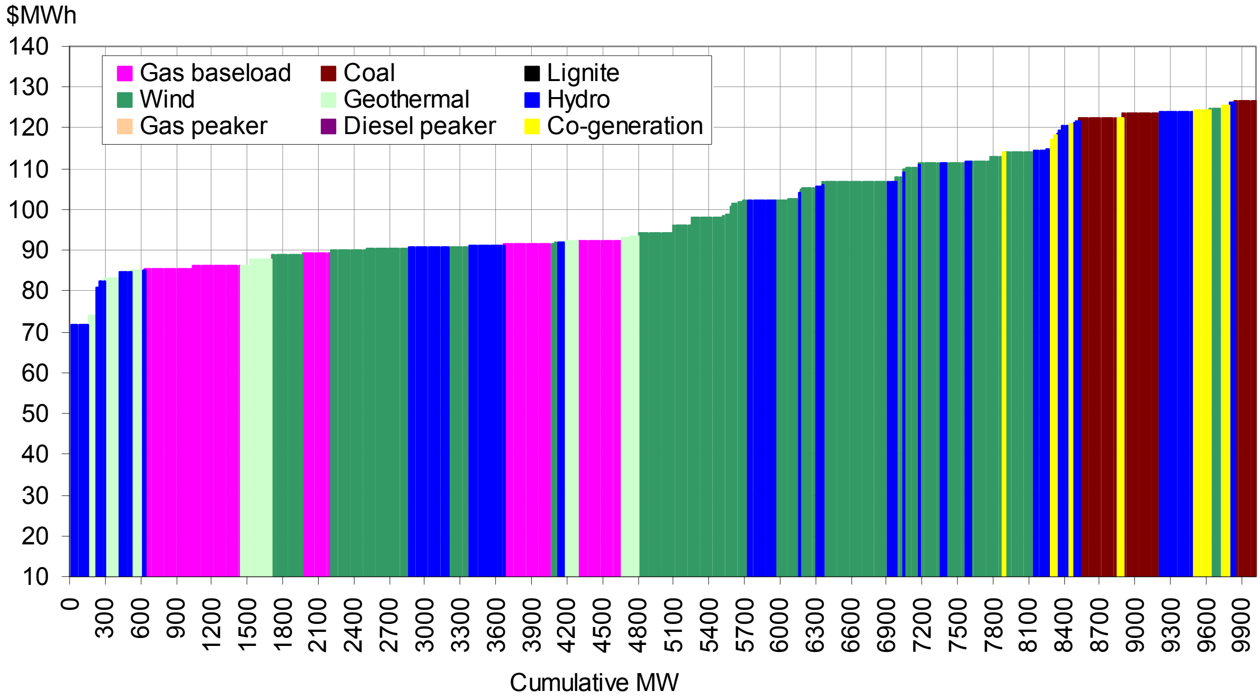
Figure 29 Break even gas prices by basin (Reference scenario)



6.2 Electricity LRMC webtool

The following is an example LRMC chart from the webtool available on the MED website (http://www.med.govt.nz/templates/MultipageDocumentTOC____41972.aspx). Users can enter their own assumptions around fuel prices, carbon price, exchange rates and capital costs to see how the LRMC responds.

Figure 30 LRMC of potential new generation plant (gas $8/GJ, carbon $50/t)



6.3 VFM Schematic