Potential Impact of Consumer Behaviour and Fossil Fuelled Hydrogen Generation on National Energy Policy of New Zealand

Jonathan Leaver  MS(Stanford) PhD (Auckland)
Dept of Civil Engineering, Unitec NZ

Luke Leaver  BE(Hons) MS(Stanford)
Asia Pacific Energy Research Centre
Acknowledgements

Researchers
• Kenneth Gillingham, AB (Dartmouth), MS (Stanford), MA (Auckland)
• Andrew Baglino BS(Hons)(Stanford)

Adviser and Dedication
• Dr Paul Kruger (Stanford) (deceased)

Project Partners
• Dr Tony Clemens (deceased) – CRL Energy
• Alister Gardner - Industrial Research Ltd
Outline

- UniSyD Model
- Scenario Results
- Conclusions

Source: http://en.wikipedia.org/
U.S. – N.Z. Economy 2009

Source: CIA – The World Factbook
Selected Resource Potential

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>Potential Added Generation (MWh/cap2010)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal*</td>
<td>119</td>
</tr>
<tr>
<td>Wind</td>
<td>30</td>
</tr>
<tr>
<td>CSP*</td>
<td>10</td>
</tr>
<tr>
<td>Nuclear</td>
<td>5</td>
</tr>
<tr>
<td>Geothermal</td>
<td>2</td>
</tr>
<tr>
<td>Hydro</td>
<td>1</td>
</tr>
<tr>
<td>Solar hot water</td>
<td>0</td>
</tr>
</tbody>
</table>

**Note:**
*Coal based on 100 years of generation. CSP=concentrated solar power.

**Sources:**
Part 2: UNISYD Model

Models NZ's Energy-Economic System

- Detailed technological specificity and resource modelling
- 1100 primary variables, 7000 lines of code
- Simulates in biweekly time steps
- 13 NZ regions

Primary Sectors
- Electricity Market
- Hydrogen Market
- Lignocellulose market
- Vehicle Fleet Market
Modelled Regions

- North Isthmus
- Auckland
- Waikato
- Taranaki
- Central
- Hawke's Bay
- Bay of Plenty
- Wellington
- Otago/Southland
- South Canterbury
- West Coast
- Canterbury
- Nelson/Marlborough
UniSyD Model Structure
Electricity Market - Overview

- **Demand**
  - Exogenous demand growth
  - Dynamic interaction with price signals

- **Supply: generation options (+sequestration option)**
  - Coal
  - Natural gas
  - Hydro
  - Geothermal
  - e-/H₂ Cogeneration
  - Biomass
  - Solar PV
  - Wind
  - Solar Thermal
  - Combined Heat and Power
  - Microgeneration
Electricity Generation

- New capacity is installed as follows:
  - Find region with most expensive retail prices
  - Determine least expensive technology for that region
  - Build a plant if
    a) the region does not already have a plant under construction, and
    b) the production cost is below the capital planning wholesale price (i.e. lowest cost additional generation)

- Technology learning curves lower production costs of future plants

- Future gas plants are only built if LNG is available
Hydrogen Market Overview

• There are 4 centralised plant types, each with 5 sizes:
  – Biomass gasification.
  – Coal gasification.
  – Coal co-generation of hydrogen and electricity using a solid oxide fuel cell topping cycle and sequestering CO2.
  – Large steam methane reforming.

• Delivery is via liquid hydrogen tankers
  – considered to be the most economic for New Zealand

• Forecourt generation includes SSMR and electrolysis
  – steam methane reforming is unavailable in the South Island, where there is no reticulated gas.
  – forecourt generators are must-use, or base load.
Lignocellulose (Forest) Market - Overview

• Bio-ethanol from forests and biodiesel from rape seed crop
• New biomass development cannot exceed the regional supply limit.
• Marginal pricing system with $H_2$ from biogasification, bioethanol and biomass electricity generation competing for the same fuel.
Vehicle Choice: Logit A – 1\textsuperscript{st} Option

- Logit choice model used for market share, $S$, of vehicle type, $i$:

\[ S_1 = \frac{\exp(\beta_1 p_1 - \gamma_1)}{\sum_i \exp(\beta_i p_i - \gamma_i)} \]

- $p$ is the annual cost
- $B$ is the price elasticity
- $\gamma$ the intrinsic preference parameter
Vehicle Choice: Logit B – 2nd Option

- The market share, $S$, is function of:
  - Fuel cost per km from ICEV
  - Purchase price from ICEV
  - Driving range (km)
  - Convenient medium range destinations requiring no advanced planning.
  - Proportion of long range destinations that can be reached.
  - Reluctance to drive ICEVs.

Note: CMDD and PLDD utility factors for EVs are sigmoid functions of the % of fleet penetration
# Vehicle Fleets

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Modelled Profile</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICEVs, $H_2$ICEVs, BICEVs, HEVs, PHEVs, BEVs, FCVs,</td>
<td>Imported Used North Island</td>
</tr>
<tr>
<td></td>
<td>Light South Island</td>
</tr>
<tr>
<td></td>
<td>New North Island</td>
</tr>
<tr>
<td></td>
<td>South Island</td>
</tr>
<tr>
<td></td>
<td>Heavy North Island</td>
</tr>
<tr>
<td></td>
<td>South Island</td>
</tr>
</tbody>
</table>
## Vehicle Fuel Economy

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Low Bound</th>
<th>New Light</th>
<th>Heavy</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ICEV/HICEV</strong></td>
<td>1.24</td>
<td>1.21</td>
<td>0.40</td>
</tr>
<tr>
<td></td>
<td>2.17</td>
<td>2.17</td>
<td>0.62</td>
</tr>
<tr>
<td><strong>HFCV</strong></td>
<td>3.09</td>
<td>3.09</td>
<td>0.89</td>
</tr>
<tr>
<td></td>
<td>3.36</td>
<td>3.36</td>
<td>0.97</td>
</tr>
<tr>
<td><strong>BEV (320 km range)</strong></td>
<td>4.50</td>
<td>4.50</td>
<td>1.35</td>
</tr>
<tr>
<td></td>
<td>5.10</td>
<td>5.10</td>
<td>1.52</td>
</tr>
</tbody>
</table>
Light Vehicle: Specific Fuel Cost

![Graph showing fuel costs over years for different vehicle types: BioEthanol, H2ICEV, Petrol, FCV, and EV. The x-axis represents years from 2010 to 2050, while the y-axis shows fuel cost in US$/km. The costs for each type are depicted with distinct lines, showing trends over time.]
Vehicle Cost and Payback

Logit A - No weighting

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Low bound</th>
<th>High bound</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turbo</td>
<td>24</td>
<td>32</td>
</tr>
<tr>
<td>Diesel</td>
<td>24</td>
<td>32</td>
</tr>
<tr>
<td>HEV</td>
<td>24</td>
<td>32</td>
</tr>
<tr>
<td>PHEV-48 km</td>
<td>24</td>
<td>32</td>
</tr>
<tr>
<td>HFCV</td>
<td>24</td>
<td>32</td>
</tr>
<tr>
<td>PHEV-96 km</td>
<td>24</td>
<td>32</td>
</tr>
<tr>
<td>BEV</td>
<td>24</td>
<td>32</td>
</tr>
</tbody>
</table>

Logit B - Consumer weighted

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Low bound</th>
<th>High bound</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turbo</td>
<td>8</td>
<td>16</td>
</tr>
<tr>
<td>Diesel</td>
<td>8</td>
<td>16</td>
</tr>
<tr>
<td>HEV</td>
<td>8</td>
<td>16</td>
</tr>
<tr>
<td>PHEV-48 km</td>
<td>8</td>
<td>16</td>
</tr>
<tr>
<td>HFCV</td>
<td>8</td>
<td>16</td>
</tr>
<tr>
<td>PHEV-96 km</td>
<td>8</td>
<td>16</td>
</tr>
<tr>
<td>BEV</td>
<td>8</td>
<td>16</td>
</tr>
</tbody>
</table>

Simple Payback:

- Turbo Diesel HEV PHEV-48: 24,000 km
- HFCV PHEV-96: 9,600 km
- BEV: 24,000 km

Extra vehicle cost (US$):

- Turbo Diesel HEV PHEV-48: 0 US$
- HFCV PHEV-96: 0 US$
- BEV: 0 US$

## Part 3: Scenario Parameters

### Base Case:
- Oil US$200/bbl by 2050
- Ctax: US$15/t-C from 2012
- New fossils with sequestration permitted but no coal to liquids

### High CTax Case:
- Oil US$200/bbl by 2050
- Ctax: US$120/t-C from 2012
- New fossils with sequestration permitted but no coal to liquids

### Table: Key Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Base Case</th>
<th>High CTax Case</th>
</tr>
</thead>
<tbody>
<tr>
<td>International Oil Price US$/bbl</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon Tax US$/t-C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>New fossils with sequestration</td>
<td>permitted</td>
<td>permitted</td>
</tr>
<tr>
<td>permitted but no coal to liquids</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Diagram:

- **Vehicle Fleets**
  - New Year FCV
  - Battery Learning Curve
  - EV Range km
  - Start Year HEV
  - Start Year BICEV
  - Start Year PHEV
  - Start Year EV

- **Fossil/Bio Fuels**
  - Year of Oil & NG Price Increase
  - Oil & NG Price Increase %
  - Start Year FCV
  - Start Year HEV
  - Start Year BICEV
  - Start Year PHEV

- **Carbon**
  - Carbon Tax 2008 US$/t-C
  - Carbon Tax 2012 US$/t-C

- **Primary Variables**
  - Mandate Fuel Economy $ per 100 KM
  - Linear Fuel Economy

- **Secondary Variables**
  - Hydrogen Production
    - Allow H2 from Cogen?
    - Allow Small SMR?
  - Electricity
    - Seasonal Hydro Power
    - Start Year Ramp Down Existing Coal
    - Start Year Ramp Down Existing Coal

- **Plant**
  - Enthusiastic H2 Plant Building
  - Mandate H2 pipelines
  - Initial EV Capital Tax %
  - Initial PHEV Capital Tax %

- **Other**
  - Liquefied Natural Gas (LNG) Importation Begins
  - Oil & NG Price Increase %
  -Tag Coal to Oil?
  - Tag Demand to Pop?

- **Additional Variables**
  - NZ$/US$ Exchange Rate
  - Random Rainfall
  - Linear Fuel Economy?
Electricity and Vehicle Fleet Profiles

Low Ctax Logit A

Low Ctax Logit B

High Ctax Logit A
Vehicle Market Variations 2050

Low CTax Logit A
- BEV: 24.4%
- PHEV: 13.9%
- FCV: 27.2%
- H2ICEV: 19.9%
- BICEV: 4.7%
- HEV: 6.7%
- ICEV: 8.7%

Low CTax Logit B
- BEV: 35.2%
- PHEV: 34.1%
- FCV: 5.0%
- H2ICEV: 12.0%
- BICEV: 4.7%
- HEV: 6.5%
- ICEV: 7.4%

High Ctax Logit A
- BEV: 25.0%
- PHEV: 28.1%
- FCV: 28.1%
- H2ICEV: 19.9%
- BICEV: 5.0%
- HEV: 13.9%
- ICEV: 9.2%
Greenhouse Gas Emissions

Low Ctax Logit A

Low Ctax Logit B

High Ctax Logit A
Conclusions

• In the base case scenario using the Logit B consumer weightings of capital and fuel costs results in a 34% increase in CVs (ICEVs, HEVs) in 2050.

• Increasing the carbon tax in the Logit A case from US$15/t-CO$_2$-eq to US$120/t-CO$_2$-eq results in:
  – Reduction of CVs from 69% to 52% by 2050.
  – A 27% increase in GHG emissions from 2010 levels due to lack of sequestration capacity.

• To counter consumer resistance to the purchase of higher priced electric drive vehicles it is advisable to capitalise fuel savings with a fuel tax and subsidise the capital cost.

• A cap and trade policy may be necessary to keep GHG emissions at or below 2010 levels due to the production of hydrogen from advanced technology plants producing hydrogen by coal gasification.
Questions?

Kereru
(Native Wood Pigeon)

Lake Pukaki & Mt Aoraki (Cook)
3,754 metres, 12,316 ft

Pohutu Geyser, Rotorua

Akaroa, South Island

Omaha Beach, North Auckland