CHEMICAL ENGINEERING TRANSACTIONS Volume 18, 2009
Editor Jiří Klemeš
 ISBN 978-88-95608-04-4 ISSN 1974-9791
DOI: 10.3303/CET0918104

Economic Impact of the Integration of Alternative Vehicle Technologies into the New Zealand Vehicle Fleet

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The prospect of significant increases in the price of imported oil combined with the need to reduce greenhouse gas emissions presents a major economic challenge to small South Pacific nations such as New Zealand that import a high proportion of their fossil fuel. This has resulted in federal policy initiatives to explore the viability of alternative energy conversion technologies for the transport fleet. This paper uses a multi-regional integrated energy systems model to assess the economic impact of hydrogen fuel cell, hydrogen internal combustion, and battery electric technologies on the economy of New Zealand and examines the sensitivity of the results to the oil price and carbon tax. The results suggest that a hydrogen fuel dominant vehicle fleet offers economic savings over a conventional fleet averaging US3.3c/km over the period 2015 to 2050 but requires the largest sequestration capacity as 75% of hydrogen fuel production is derived from fossil fuel. In the sensitivity study the oil price path is varied, resulting in US$120 to US$240 per barrel in 2030, and the carbon tax varied from US$30 to US$90 per tonne of CO_2 equivalent. The change in savings ranges from -65% to +25%.

Introduction

New Zealand consists of two main islands in the South Pacific with a total population of 4.28 million people (Statistics New Zealand, 2008) and a total land area of 269,000 km^2. Small island nations such as New Zealand have traditionally relied heavily on imported oil to fuel the transport fleet and provide primary energy for peak load electricity generation. In 2007 70% of the total of 751 PJ of primary energy used in New Zealand came from fossil sources (Ministry of Economic Development, 2007a) and New Zealand's transport fleet totaled 3.3 million motorized vehicles of which 2.6 million were passenger cars and vans (Land Transport New Zealand, 2008).
In the electricity sector New Zealand has an abundance of renewable resources with future additional generation capacity at a price less than 9.6 USc/kWh estimated as high as 202 PJ in 2025 (East Harbour Management Services, 2005) which is 130% of the total electricity demand in 2006 (Ministry of Economic Development, 2007a).
As a signatory to the Kyoto Protocol (United Nations, 1998), New Zealand is required to maintain greenhouse emissions no higher than 1990 levels for the five year period

Please cite this article as: Leaver J. and Gillingham K., (2009), Economic impact of the integration of alternative vehicle technologies into the new zealand vehicle fleet, Chemical Engineering Transactions, 18, 641-646 DOI: 10.3303/CET0918104

from 2008 to 2012. In response to meeting this commitment and to mitigate concerns both about ensuring security of energy supply and the economic impact of a high oil price the federal government has targeted the replacement of up to 73% of the conventional vehicle fleet by 2050 with alternative battery or hydrogen powered electric vehicles (Parker, 2008; Ministry of Economic Development, 2007b)

Model Development

The UniSyD model of New Zealand's energy and economic systems is a multi-regional partial equilibrium model developed with system dynamics software (High Performance Systems, 1997) to evaluate the impact of alternative vehicle technologies in New Zealand's fleet. The model is constructed with modules that incorporate key sectors of the energy economy and parameterized specifically for New Zealand.

In the primary resources sectors the determination of demand, extraction and importation, pricing, and allocation is made. Resources are demanded in response to price signals and are then allocated into one of the 13 different regions based on on both price and priority of use, with the highest priority being reticulated residential, followed by commercial and industrial consumers. Demand is roughly equilibrated with supply in all markets at each time step.

1.1 Electricity and Hydrogen Production

The electricity sector of the model is driven by a statically defined demand growth and the dynamic interaction of predicted growth with price signals coming from the generation and pricing sectors. Electricity demand increases at a constant ratio to population growth modified by a price elasticity of 2% reduction in demand for each 6 USc/kWh price increase. New fossil based electricity generating plants are installed in sizes ranging from 200 MW to 600 MW.

In the model hydrogen is produced on the forecourt by electrolysis or steam methane reforming or on a larger scale by centralised production using coal or biomass gasification and steam methane reforming. Centralised co-generation of hydrogen and electricity using coal gasification and a solid oxide fuel cell topping cycle is also included. Transport to retail stations is by cryo-tankers as widespread pipeline distribution is considered unlikely due to the low population density of New Zealand (Yang and Ogden, 2007). The development of both production types is matched to the hydrogen demand and prices of individual production techniques. There are separate markets for hydrogen in the North and South Islands.

Forecourt production options are always the first constructed, as initial demand is small. Later large scale centralised hydrogen production plants are built using biomass or coal gasification, cogeneration of hydrogen and electricity or steam methane reforming of natural gas at mass production rates of 75, 100, 200, 400, or 800 tonnes per day.

Prediction of hydrogen demand is based on a three year moving average and is made for a point three years into the future. Cogeneration plants can offset high capital costs by selling electricity back to the grid as a co-product to hydrogen production.

The principal outputs of the model are profiles of electricity and hydrogen generation, vehicle fleet numbers, electricity and hydrogen production prices, greenhouse gas emission volumes, primary energy use, water and air pollution costs. The model is run with bimonthly time steps.

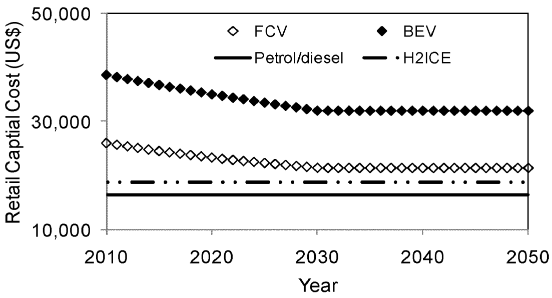

Figure 1. Retail capital cost profiles for vehicle technologies (Leaver et al., 2009).

1.2 Vehicle Fleet

The model incorporates four separate vehicle technologies. These are gasoline internal combustion (ICEV), hydrogen internal combustion (HICEV), hydrogen fuel cell (FCV) and battery electric vehicles (BEV). For each technology there is a fleet of new light vehicles, imported light vehicles, and heavy vehicles. Light vehicles are divided into new and imported vehicles due to the different retail cost of each fleet. In 2007 61% of the vehicle fleet in New Zealand was imported with an average age of seven years (Land Transport New Zealand, 2008). Each technology also has a separate fleet in the North and South Islands. A light ICEV weighs less than 3.5 tonnes tare weight, has an engine power of 110 kW and has an untaxed retail price of US$16,360. BEVs and FCVs are modelled with two thirds of the electric motor power of an ICEV as this would provide roughly equal torque characteristics for all technologies under city driving conditions.

Retail price profiles for all vehicle technologies are shown in Figure 1. The retail capital price is determined by subtracting 38% of the total price that is specific to a conventional ICEV drivetrain (Cuenca et al., 1999) and adding drivetrain specific costs for BEVs and FCVs (Kromer and Heywood, 2006).The BEV is assumed to have a range of 320 km in order to be equivalent in functionality to the average ICEV and not incur consumer resistance due to reduced range.

In this study the UniSyD model is used to conduct a sensitivity study of vehicle numbers and costs, greenhouse gas emissions, and fossil fuel use, to variations in the price for offsetting the emission of a tonne of carbon dioxide equivalent (t-C), and in the price of oil. Five scenarios are defined in Table 1.

In each of the scenarios the impact of competition from HICE, FCV, and BEV fleets on the ICE fleet is examined.

Table 1. Scenario definitions

	Oil Price in 2008		
	US$60/bbl	US$90/bbl	US$120/bbl
US$30/t-carbon	-	LowC	-
US$60/t-carbon	LowOil	Base	HighOil
US$90/t-carbon	-	HighC	-

The following key assumptions apply for all scenarios:

- A 3% increase in the price of oil is assumed from 2008 with a maximum increase of 100%, reflecting the expected long-run trend for oil.
- Natural gas and coal prices are assumed to follow the same price trend as oil.
- The price in 2008 for coal is assumed as US$2.40/GJ with the price for natural gas as US$4.65/GJ.
- Sequestration costs after capture and storage in depleted gas fields, uneconomic coal seams or deep saline aquifers, range from US$1.60/t-C for early storage to US$16.30/t-C (Intergovernmental Panel on Climate Change, 2005) as sequestration volumes approach the available capacity.
- No new fossil fuelled stations are permitted before 2018 in line with federal government policy of 2008.

Results

In order to identify technology specific trends each scenario is run to 2050 with only one of the new vehicle technologies competing against conventional ICEVs. Figure 2a shows the proportion of ICEVs in the vehicle fleet for each scenario.

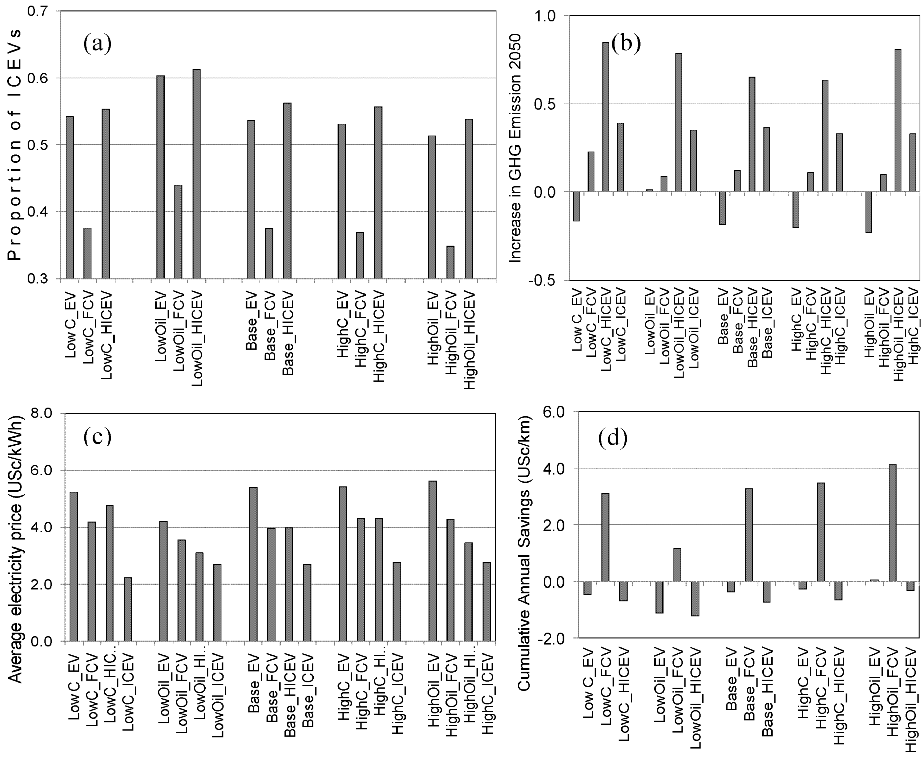

Figure 2. (a) Proportion of ICEVs in the vehicle fleet in 2050. (b) Reduction in greenhouse gas emissions from 2009 to 2050. (c) Average electricity price 2020 to 2050. (d) Cumulative average savings in vehicle costs 2015 to 2050.

Figure 2a emphasises that the carbon tax has much less influence on the number of ICEVs than the oil price. A carbon tax of US$90/t-C represents about 36% of the petrol price when the oil price is US$90/bbl. In 2050 ICEVs are reduced to about 35% in competition with FCVs but only to an average of 52% and 57% for BEVs and HICEVs respectively.

Figure 2b shows the increase in greenhouse gas emissions. In a conventional ICEV fleet, greenhouse gas emissions increase between 33% and 39% between 2008 and 2050. Only the introduction of BEVs into the vehicle fleet results in a reduction of greenhouse gas emissions over 2008 in the range 0% to 23%, depending on the oil and carbon price. This reduction is the result of nearly 100% renewable electricity generation in 2050 with wind, hydro and geothermal being the dominant primary energies. The adoption of FCVs and HICEs results in increases in greenhouse gas emissions of between 0% and 22% and between 65% and 85% respectively. The large scale production of hydrogen fuel for FCVs in the base case involves 62% coal co-generation, 34% electrolysis, and 4% biogasification.

The proportion of emissions sequestered in 2050 over all the scenarios for both FCVs and HICEVs ranges from 8% to 14% with sequestration peaking at 43% in 2034. After 2034 the proportion of emissions sequestered reduces due to a lack of sequestration capacity for high volume greenhouse gas emissions from coal fired hydrogen-electricity cogeneration plants that account for about 75% of hydrogen production following the initial decade of forecourt production by electrolysis and steam methane reforming.

Figure 2c shows that the adoption of BEVs results in marginal electricity prices rising 156% to 235% higher than for the ICEV only scenario while the adoption of FCVs results in marginal electricity prices rising by 133% to 188%. These substantial increases in electricity prices are primarily due to the additional electricity demand from both BEVs and the production of hydrogen by electrolysis with the price increase lower for FCVs due to the lower cost of electricity production from coal fuelled cogeneration of electricity and hydrogen.

Figure 2d shows that only FCVs have positive average cumulative savings of 3.3 USc/km for the period 2015 to 2050 compared to the ICEV base scenario. BEVs and HICEVs produce average costs of 0.4 USc/km and 0.7 USc/km respectively. The principal advantages of FCVs are firstly that the capital cost is about 34% lower than BEVs (Figure 1) and secondly that the fuel consumption that is less than half that of ICEVs (Kromer and Heywood, 2006). Savings for other scenarios range from -65% (1.2 USc/km) for the LowOil scenario to +25% (4.1 USc/km) for the HighOil scenario.

Conclusions

The multi-regional, partial equilibrium, system dynamics model, UniSyD, has proven to be a useful tool to model New Zealand's energy economy and gain insight into various energy futures. The sensitivity study of five scenarios in which the carbon tax was varied from US$30/t-C to US$90/t-C and the oil price varied from US$60/bbl to US$120/bbl yields the following key results:

- Permitting BEV technology to compete with ICEV results in reductions between 2008 and 2050 in energy and transport sector greenhouse gas emissions of up to

23%. In comparison, emissions in the FCV and HICEV scenarios increased by up to 22% and 85% respectively.

- The FCV and HICEV scenarios use sequestration for up to 43% of emissions in the period 2020 to 2050.
- The BEV scenarios resulted in the highest increases in electricity of up to 235% over the ICEV scenarios while the FCV and HICEV scenarios resulted in increases of up to 188% and 214% respectively.
- FCVs have positive average cumulative savings for 2015 to 2050 of 3.3 USc/km, due to the expected improvement in the cost of the technology, while BEVs and HICEVs produce average costs of 0.4 USc/km and 0.7 USc/km respectively.

This study shows that FCVs are the preferred technology based on average cumulative savings. BEVs are preferable if the highest priority is to minimize greenhouse gas emissions. However policymakers may also consider investing some of the savings from using FCVs in carbon credits, possibly resulting in lower emissions and costs.

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