

# POTENTIAL IN NEW ZEALAND FOR USE OF HYDROGEN AS A TRANSPORTATION FUEL

Paul Kruger, John Blakeley, and Jonathan Leaver<sup>1</sup>  
School of Civil and Environmental Engineering  
UNITEC Institute of Technology  
Auckland, New Zealand

*New Zealand imports its vehicle fleet and essentially all transportation fuel. With introduction of fuel-cell vehicles, New Zealand can become self sufficient in hydrogen fuel. A study undertaken by the Sustainable Energy Initiatives program at UNITEC evaluates the economic and environmental factors of fossil and non-fossil energy sources for production of hydrogen. It examines the transition for hydrogen fuel from on-board production from hydrocarbons to large-scale centralised electrolytic production. The paper extrapolates historic data on population, vehicle transport, and electric energy and examines the basis for introducing hydrogen fuel into the national economy in the 2010 – 2050 period.*

[Abstract](#)

[Transcript](#)

[Back to Contents](#)

## 1. Introduction

Motor vehicle transportation plays an important role in the economy of New Zealand, one of the smaller nations in the Organisation for Economic Co-operation and Development (OECD). Except for a period of local assembly of automobiles through to the 1990s, New Zealand has imported all of its vehicle fleet. In addition to purchase of new vehicles from the major automobile producers throughout the world, New Zealand now imports a large fraction of its fleet as pre-owned trade-in vehicles from abroad. Since the country has only limited indigenous petroleum reserves and refining capacity, import of transportation fuels is a major cost factor in the national economy. Further, New Zealand has officially declared that it will strongly attempt to meet its goal for reduction of CO<sub>2</sub> emission to the global atmosphere under international agreements and local authorities are becoming more aware of growing air pollution problems from smog producing emissions in the major metropolitan areas.

These factors have made the potential for introducing hydrogen fuel as an alternate to fossil fuel of great interest to small-developed countries, such as New Zealand. Although there are no plans for the future to introduce manufacture of automobiles and other vehicles in New Zealand, the potential exists for development of an indigenous industry to produce hydrogen fuel in large-enough quantity to provide several benefits:

---

<sup>1</sup> School of Civil and Environmental Engineering, UNITEC Institute of Technology, Auckland, New Zealand

- (1) Introduce a new industrial program into the New Zealand economy,
- (2) Reduce the import-export imbalance with an indigenous supply of transportation fuel,
- (3) Provide an opportunity for export of hydrogen fuel to surrounding Pacific area countries,
- (4) Reduce the magnitude of CO<sub>2</sub> emission to the atmosphere,
- (5) Reduce the emission of smog-forming nitrogen oxides in metropolitan areas,
- (6) Accelerate planning for additional electric energy supply from non-fossil fuel resources.

To evaluate the technical, environmental, and economic aspects of the potential for introducing an industrial endeavour to produce hydrogen fuel in New Zealand, a research project was begun in the Sustainable Energy Initiatives program in the School of Civil and Environmental Engineering at UNITEC Institute of Technology in Auckland, New Zealand. The project was initiated as a means for students in the school to satisfy the research requirement for degree completion. The first year effort was designed to compile and analyse the necessary data on New Zealand population, motor vehicle fleet composition, vehicle traffic, fuel economy, methods of hydrogen production, electricity generation and installed power capacity, and examine the infrastructure needed for central and distributed refuelling facilities. The project began with a suite of five research studies undertaken by seven students in the school. Their research results, detailed in references [1] to [5], are incorporated in this paper which presents the first-year analysis of the potential for introducing hydrogen fuel into the New Zealand national economy over the 2010 – 2050 time period.

## **2. Historic Database for Transportation in New Zealand**

Analysis of the potential for utilisation of hydrogen fuel in New Zealand requires estimation of the magnitude of motor vehicle transportation in the future when import of fuel-cell vehicles could become significant. However, import of fuel-cell vehicles will require immediate availability of hydrogen fuel. During some transition period until large-scale hydrogen production facilities are constructed, on-board fossil-fuel reforming could be used in early model vehicles to provide the hydrogen fuel. These may be the most likely vehicles to be imported for several decades.

But the plans for long-term preparation of hydrogen production, distribution, storage, and refuelling facilities needs to be initiated in time to ensure that the economic investment is justified and that sufficient resources and electric power are available initially for fossil-fuel reforming on either a very small scale (individual vehicles) or a large scale and subsequently for water electrolysis. The historic data required to analyse the potential for fuel-cell vehicles in New Zealand includes magnitudes and growth rates of population, vehicle fleet by type, annual travel and fuel economy by type, and electric energy supply and power capacity. These data are being compiled from official government sources.

The values for the year 2000 and the mean annual growth rates are used as initial values in a dynamic model [6] to extrapolate them to the year 2010 when a significant fuel-cell fleet could begin to develop in New Zealand. Estimations are made for the potential of rapid growth of a hydrogen fuel industry over the next 40 years. The results are evaluated to examine the need for additional growth of electric power to sustain this growth industry.

### **(1) Population**

Population data are available from the series of New Zealand Official Yearbooks [7] and data from statistics New Zealand [8] compiled in [4]. The population of New Zealand in 1980 was 3.14 million

people and has grown steadily at m.a.g.r. of 1.08 %/a through 2000. The population in 1990 was 3.363 million people growing at m.a.g.r. of 1.34 %/a. The population in 2000 was 3.86 million people and the projected m.a.g.r. through 2010 [8] given in [4] is 0.70 %/a. An extended forecast [8] shows a maximum population around 2035 and decline thereafter, which is used with expectations for conservation, to estimate the comparative potential for the 2010-2050 period.

## **(2) Vehicle Fleet**

Vehicle fleet data are available from the Land Transport Safety Authority [9]. Detailed compilations were obtained for the period 1990 to 2000 by vehicle type [4] and engine size and fuel type [5]. The number of licensed vehicles in New Zealand at the end of 2000 was 2.78 million, of which 1.94 million (70 %) were automobiles, with about 13 % trucks, 13 % trailers, 17 % motorcycles and mopeds, and 0.5 % buses. The growth rate for automobiles and vans (characterised herein as light vehicles) over the ten-year period was 2.22 %/a; the growth rate for heavy vehicles (trucks, trailers, and buses) was 0.87 %/a. The data also show a marked shift in vehicle engine size from an average of 2000 cc in 1997 to 2140 cc in 1998. Most of the fuel used is petrol (gasoline) comprising about 85 % of fleet consumption and diesel (almost 15 %), the remainder (0.15 %) consists of about 4000 alternate fuel vehicles using, e.g., LPG, CNG, and electric batteries [5]. Another key statistic is the age distribution, which greatly affects the fleet fuel economy. The average of all categories of licensed motor vehicles (excluding trailers) is about 12 years. Projected vehicle fleet growth through 2021 was estimated [4] to reach 3.73 million vehicles at m.a.g.r. of 1.32 %/a. In the scenario step of the study, the extended forecast of population was used to estimate the reduced fleet size under the conditions of conservation compared to business-as-usual growth.

## **(3) Annual Travel Distance**

Fuel and energy requirements for transportation depend strongly on the total annual travel distance. Travel data are generally sparser than vehicle registration data. The Land Transport Safety Authority conducted travel surveys [10] in 1989/90 and 1997/98 for automobiles and vans. Travel statistics are available from the Ministry for the Environment [11] for both light vehicles (cars and vans) and heavy vehicles (trucks, trailers and buses). Data for 1980 through 2000 were compiled [4] for both types of vehicle. Light vehicle travel accounted for about 75 % of the total travel in this period, reaching a value of 31.3 billion vehicle kilometres travel (BVKT) in 2000 at m.a.g.r. of 3.52 %/a in the past decade. The value for heavy vehicles was 9.44 BVKT at m.a.g.r. of 3.61 %/a. These large growth rates (with a doubling period of about 20 years) indicate that annual travel distance will play an important roll in the 2010-2050 period.

## **(4) Fuel Economy**

Statistical data for on-road fuel economy in New Zealand are sparse and mean values have large standard deviations due to such problems as national fleet composition, vehicle age distribution, and variations in emission control methods. For New Zealand fuel economy, data from the Ministry of Economic Development [12], as noted in [5] gives an average fuel consumption for the petrol fleet of 10 km/L, corresponding to a fuel economy of about 23.5 mi/USgal. This value is significantly larger than the mean of 17.8 mi/gal estimated for 2000 in the United States. Since detailed fuel economy data was not available, the extrapolation of fuel economy is based on the U.S. Environmental Protection Agency's 'laboratory-measured' fuel economies for world-wide produced vehicles sold in the United States, adjusted for the ratio of greater fuel economy in New Zealand. The resulting 2000 values for New Zealand are 28.8 mi/gal for light vehicles and 8.4 mi/gal for heavy vehicles with corresponding m.a.g.r. of 1.86 %/a and 0.82 %/a.

### **(5) Electricity Supply**

Electric energy and installed power capacity data are available from the Modelling and Statistics Unit of the Ministry of Economic Development [12] as reported in the joint SKM&CAE publication [13] on energy forecast through 2015. Data for 1990 to 2000 show an increase in electric energy generation from 31.0 to 37.5 TWh at m.a.g.r. of 1.98 %/a and an increase in installed electric power capacity from 7.0 to 8.5 GW at m.a.g.r. of 1.86 %/a. In 2000, the energy resources to produce the electricity supply consisted of hydroelectric (67 %), thermal (26 %), geothermal (6.3 %), wind and other (0.7 %).

### **(6) Environmental Emissions from Motor Vehicles**

The health effects of environmental pollution from motor vehicle exhaust as well as concerns about global climate change from emission of carbon dioxide could play an important externality role in the potential for replacing fossil fuels with hydrogen fuel in New Zealand. The Auckland Regional Council [14] notes that Auckland has one of the highest asthma rates in the world and that nitrogen oxide levels exceed standards at peak traffic sites. The New Zealand Government takes its responsibility on carbon dioxide release under the Kyoto Protocol of the Framework Convention on Climate Change very seriously and many government departments are involved in planning for reduction in CO<sub>2</sub> emission. Although the environmental aspects of vehicle emissions are not included in this paper, they are of great importance in the UNITEC project [1], [2], [3].

## **3. Initial Conditions in 2010 for Introduction of Fuel-Cell Vehicles**

To estimate the requirement for hydrogen fuel and concomitant electric energy to produce it on a sustainable long-term basis, the model used for the United States [6] was adopted for New Zealand. The model runs in two time sequences. The first uses the historic data, summarised in the preceding section, for extrapolation to the year 2010, when the importing of fuel-cell vehicles could become significant. The second time sequence uses the results as the initial conditions to examine a range of possible fuel-cell vehicle growth rates over the next 40 years to 2050 to estimate the hydrogen fuel demand for large-scale substitution of petrol and the additional electric energy required, based on anticipated technology improvement in electrolytic production of hydrogen.

The input data to the model are summarised in Table 1. In the first step of the model, extrapolated vehicle ownership is checked against calculated ownership obtained as the product of the steadily growing population and saturation growth rate of per-capita vehicle ownership attributed to limits in affluence as the population grows. For the study, the model considers two types of vehicles, as compiled by the United Nations, light weight (automobiles and vans) and heavy weight (buses, trucks, and trailers). The annual data for the two weight categories are combined with the respective vehicle traffic and fuel economy data to calculate the total fuel demand, expressed in billion gallons of petrol. In the second time sequence, the fuel demand for fuel-cell vehicles is converted to billion kilograms of energy-equivalent hydrogen. The required annual electric energy consumption is calculated with mean conversion factor data obtained from several manufacturers of electrolyser systems as a graphic input function. The calculated electric energy requirement is compared to the extrapolated “business-as-usual” national growth of electric energy demand to determine the energy and installed capacity shortfall, if any.

A summary of the output results for the first time step is also given in Table 1. The values show the

“business-as-usual” extrapolations for New Zealand motor transportation without consideration of the strong advocacy effort being made by the New Zealand Energy Efficiency and Conservation Authority (EECA) [16] to reduce the growth rate of transport and energy consumption. Comparison of the values is shown, where available from government agencies.

**Table 1. Input Parameters and Output Extrapolations from Model for 2000-2010**

Parameter (Units)	Initial Value (2000)	Growth Rate (%/a)	Output Value (2010)	Comparisons [Ref]
Population (10 <sup>6</sup> )	3.84	1.27	4.36	4.04 [4]
Ownership (VpC)				
Light Vehicles	0.53; max: 0.60	1.02	0.54	
Heavy Vehicles	0.195; max: 0.25	-0.33	0.20	
Fleet Size (10 <sup>6</sup> )				
Automobiles	2.04	2.22	2.36	
Fleet	2.78	1.84	3.24	3.21 [4]
Travel Distance (10 <sup>9</sup> VKT)				
Light Vehicles	31.3	3.52	44.2	
Heavy Vehicles	9.44	3.61	13.5	
Fleet			57.7	
Fuel Economy (km/USgal, petrol)				
Light Vehicles	46.3	1.86	55.7	
Heavy Vehicles	13.5	0.82	14.7	
Fuel Consumption as petrol (10 <sup>9</sup> gal)			1.7	
Electrolyser Eff. (kWh/Nm <sup>3</sup> )	4.5	constant	4.5	
Electricity				
Energy Demand (TWh)	37.2	1.70	44.0	43.8 [14]
Installed Capacity (GW)	8.51	180	99.2	9.69 [14]

#### 4. Scenarios for Hydrogen Fuel and Electricity Demand 2010-2050

Since a large fraction of the imported New Zealand vehicle fleet is pre-owned vehicles, a significant time lag may occur in growth of hydrogen-fuel vehicle ownership following the introduction of production of fuel-cell vehicles in the 2003-2005 period. If public acceptance of fuel-cell vehicles takes place world-wide, automobile manufacturers will accelerate their production and import into New Zealand might be expected by 2010. Step 2 of the demand model uses the extrapolated results of Step 1, listed in Table 1, as the initial conditions to examine a range of possible fuel-cell vehicle growth rates over the next 40 years to estimate the hydrogen fuel demand for large-scale substitution of petrol and diesel fuels and the additional electric energy required to achieve it based on anticipated improvement in electric energy consumption in hydrogen production by water electrolysis. The results serve as the basis for evaluating the means for planning the infrastructure for a fuel-cell fleet and the best way to produce hydrogen fuel for the expected primary energy resources in New Zealand.

The “business-as usual” conditions in 2010 might not be sustainable over the next forty years as agreed by EECA [16]. Thus, a second set of scenarios was run with the basis that the rate of growth of population would peak during this period and that conservation would reduce the per-capita ownership of motor vehicles. The forecast data for population based on the Statistics New Zealand [4] model of

medium fertility, mortality, and migration was used with saturation growth of vehicles per capita to provide a more conservative estimate of the growth of electric energy and power requirements for the scenario range of growth of a hydrogen fuel-cell vehicle fleet in New Zealand.

For the scenarios, it was assumed that early fuel-cell vehicles imported into New Zealand will be those that can be centrally refuelled, both for light vehicles (e.g., taxis, ambulances, delivery vans) and heavy vehicles (e.g., city buses, delivery trucks, heavy construction vehicles). The initial number of each type was selected as 5000 in 2010. Although this number is arbitrary, the output of the model can be scaled for any other initial value of either type of vehicle. Fuel economy was selected for the two types of vehicle from the literature [6], 80 mi/kg(H<sub>2</sub>) for lightweight vehicles and 40 mi/kg(H<sub>2</sub>) for heavyweight vehicles. Annual travel was held constant from 2010 at initial conditions, with growth offset by conservation. A major factor in the economic success of large-scale electrolytic production of hydrogen, besides the price of electricity, is the efficiency of electrolysis. In the model, a linear gradient of the energy requirement for electrolysis of water for hydrogen production from 4.5 kWh/Nm<sup>3</sup> to 3.5 kWh/Nm<sup>3</sup> was introduced to allow for technology improvement [6] in large-scale electrolyser systems. The scenarios cover the range of mean annual growth rates from 10 %/a (essentially non-growth with respect to substitution of hydrogen for fossil fuel compared to the normal growth in consumption) to 30 %/a (representing a national commitment to replace fossil fuels for economic as well as environmental reasons over the 40-year period). At the higher growth rates, the model uses saturated exponential growth to asymptotically approach the extrapolated growth of the New Zealand vehicle fleet.

## 5. Results of the Scenario Analyses for 2010-2050

The model was run for the two sets of assumptions on sustainability for the two classes of vehicle with 5000 vehicles each in 2010 at production growth rates of 10, 20 and 30 %/a through 2050. Calculations were made annually and the output was compiled at five-year intervals as fleet size, hydrogen fuel demand, electric energy consumption and equivalent power capacity requirement. A summary of the results of the fuel-cell vehicle fleet and hydrogen fuel demand for the two sets of scenario conditions is given in Table 2. The growth of the fuel-cell fleet for the business-as-usual conditions in comparison to the conventional fleet is shown in Figure 1. The growth of the corresponding hydrogen fuel demand is shown in Figure 2. Comparison of the fuel-cell fleet at m.a.g.r. 30 %/a for business-as-usual conditions and conservation conditions is shown in Figure 3. Comparison of the corresponding growth of hydrogen fuel demand is shown in Figure 4.

The results for the requirements of electric energy and the necessary additional installed power capacity are summarised in Table 3. Comparison of the electric energy demand at m.a.g.r. 30 %/a for business-as-usual conditions to that for conservation conditions is shown in Figure 5. Comparison of the corresponding growth of required total installed electric power capacity for the two sets of scenario conditions is shown in Figure 6.

**Table 2. Fuel-Cell Vehicle Fleet and Hydrogen Fuel Consumption**

Year	Conventional Fleet		Hfleet m.a.g.r (%/a)	Hydrogen Fleet		Hydrogen Fuel Demand	
	b-a-u* (10 <sup>6</sup> )	cons. (10 <sup>6</sup> )		b-a-u* (10 <sup>6</sup> )	cons. (10 <sup>6</sup> )	b-a-u* (10 <sup>9</sup> kg)	cons. (10 <sup>9</sup> kg)
2010	3.24	3.07					
2030	4.54	3.52	10-30	0.01	0.01	0.00	0.00
			10	0.07	0.07	0.02	0.02
			20	0.35	0.34	0.09	0.09
			30	1.28	1.24	0.34	0.33
2050	6.56	3.71	10	0.40	0.40	0.10	0.10
			20	4.00	3.00	1.21	0.86
			30	6.09	3.68	1.92	1.08

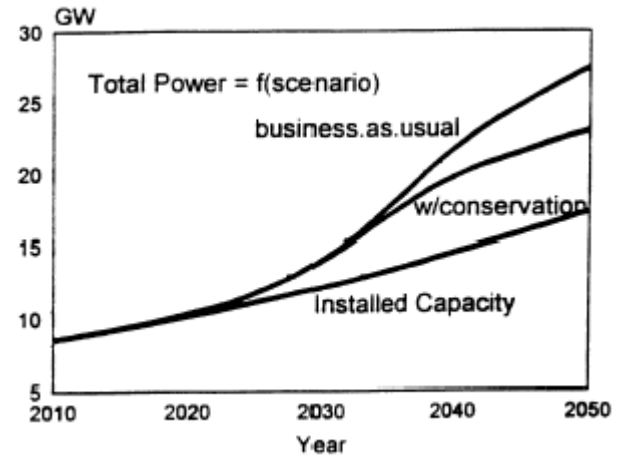
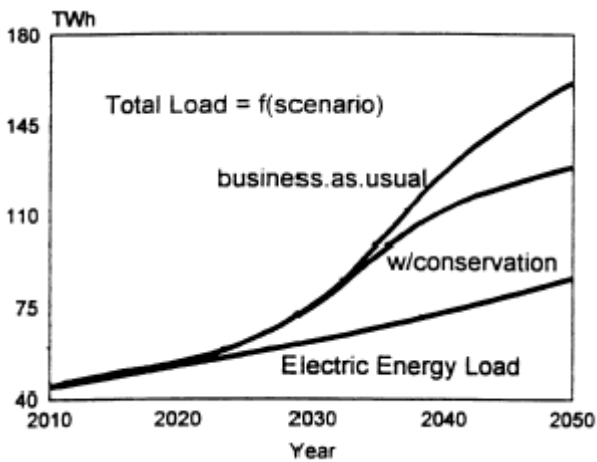
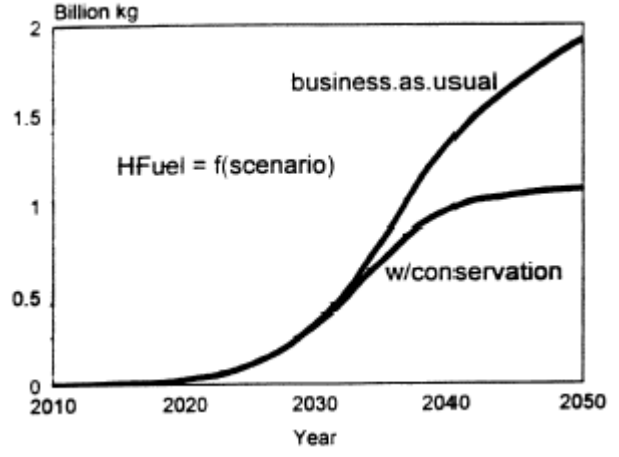
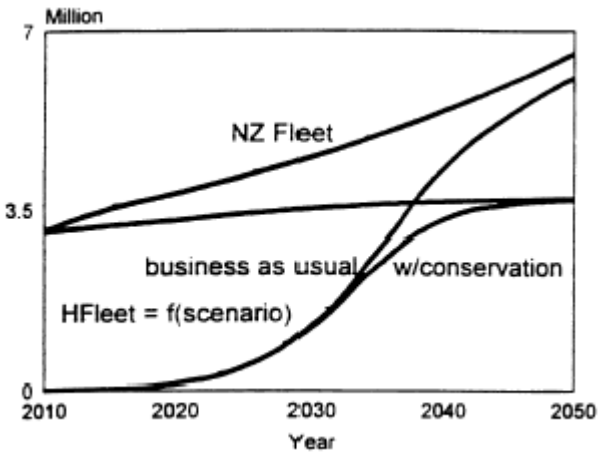
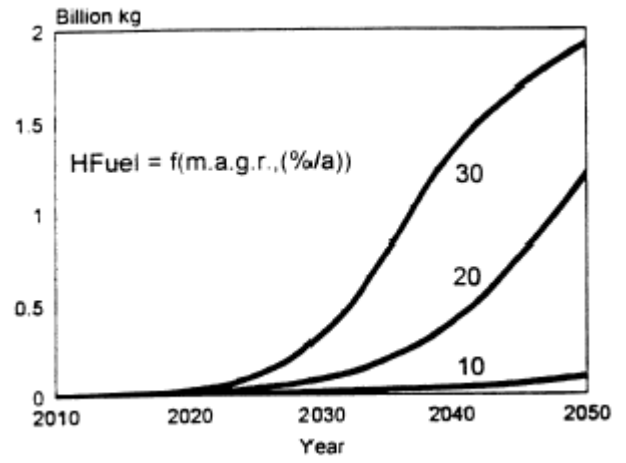
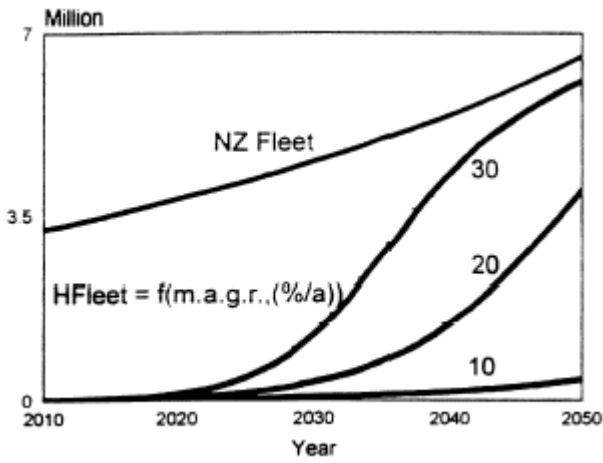
\* b-a-u = business-as-usual conditions  
 cons. = with conservation conditions

**Table 3. Electric Energy and Installed Capacity Requirements**

Year	Elec. Energy Load (TWh)	Helectricity m.a.g.r. (%/a)	Helectricity		Installed Capacity (GW)	HElectric Power	
			b-a-u* (TWh)	cons. (TWh)		b-a-u* (GW)	cons. (GW)
2010	44.0				8.51		
2030	616	10-30	0.11	0.11	12.2	0.01	0.01
		10	0.68	0.68		0.09	0.09
		20	3.64	3.61		0.49	0.48
		30	14.3	13.7		1.92	1.84
2050	86.4				17.4		
		10	3.98	3.91		1.53	0.52
		20	47.5	33.6		6.37	4.51
		30	75.2	42.3		10.1	5.67

\* b-a-u = business-as-usual conditions  
 cons. = with conservation conditions

Tables 2 and 3 indicate that for the assumed starting importation of 10,000 fuel-cell vehicles in 2010, the contribution to reducing dependence on fossil fuels will be small at any import growth rate until about 2030. After then, replacement by hydrogen-fuel vehicles could accelerate at diminishing import rates under conservation conditions so that by 2050 the remaining fossil-fuel vehicles could be retired.



This scenario allows for early planning and implementation to develop the infrastructure for a fuel-cell vehicle industry (sales and maintenance) with provisions for gradually constructing hydrogen production facilities and distribution networks. Since early model imports will be vehicles with on-board hydrogen obtained from reforming of fossil fuels (methanol, natural gas, or petrol), the industry could be developed with conventional chemical plants while large-scale electrolysis systems are developed. The major questions for evaluating the potential for a change-over to a fuel-cell vehicle industry will be: (1) can the industry gear up over the next 20 years to produce one to two billion kg of hydrogen per year on a sustainable basis; and (2) will there be sufficient energy sources available to generate the required electric energy load to produce hydrogen (40 to 70 TWh per year) as well as the growth in the other sectors of the economy (86 TWh per year) by 2050?

## **6. Energy Supply for a Fuel-Cell Vehicle Industry**

The dedication of the New Zealand government to comply with its responsibility under the Kyoto Protocol of the Framework Convention on Climate Change severely limits the country's ability to continue to increase the use of fossil fuels to meet the anticipated growth of electric energy over the foreseeable future. As noted by Blakeley [17], domestic transport accounts for 45 % of the energy-derived CO<sub>2</sub> emissions and is predicted to increase its share of total energy use. He concludes that the key to controlling future increases in New Zealand's energy use (and carbon dioxide emissions) is to limit the growth of both private cars and road freight transport. The model used in forecasting electricity supply and demand to 2015 [14] predicts, especially for dry (hydroelectric) years, that additional thermal (fossil fuel) generation will have to be used. The model also predicts that by 2007 new capacity will be required with large annual increments needed from 2009 to meet the expected reduction in natural gas supply. A review of the energy supply data in [5] shows only two main primary sources: fossil fuels (oil, gas, and coal) and renewables (hydroelectric, wind, and geothermal) and three main processes to produce hydrogen: water electrolysis, fossil fuel reforming (e.g., of methane, coal, or petrol), and advanced thermal and biological methods.

The results of this study clearly indicate that if a concerted effort is to be made in New Zealand to conserve energy and meet the goal of reducing carbon dioxide emissions, the potential to convert the fossil-fuel vehicle fleet to a hydrogen-fuel vehicle fleet must be very high. Then the potential to reduce the import of petroleum-based fossil fuels and replace the transportation fuel with indigenously produced hydrogen must also be very high. If the fossil fuel source of primary energy is reduced, then the shortfall and growth must come from the remaining primary source: renewables. This is the approach taken in Iceland [18] where a national effort is underway to change to a hydrogen-fuel economy based on development of its hydroelectric and geothermal resources.

Thus the key question for New Zealand to resolve is whether available renewable energy resources are sufficient to meet the needed total electric energy demand. This could be from hydroelectric, wind, and geothermal energy, possibly from wood (or biomass), and in the longer term from solar, wave, or tidal energy. New Zealand has large deposits of coal that could be used by chemical reforming as an alternative to water electrolysis to produce hydrogen.

Reforming might be more economical and energy efficient if the total electric energy demand cannot be obtained from renewable sources at economic cost. The corollary question of extent of carbon dioxide emission would require further study. The only other practical primary energy resource is the earth's fissionable elements (uranium and thorium). With New Zealand as a declared nuclear-free nation, it would require a national awareness of the difference between military and civil applications of nuclear energy and acceptance of nuclear energy in the nation's energy mix. This question has been raised in a recent New Zealand Herald article [19], which suggests that nuclear power is the best option to solve many problems as electricity demand outstrips supply.

The problem of how to resolve the question of how to meet anticipated growth of electric energy demand was addressed by Kruger [20] for replacing fossil fuel in vehicles on a world-wide basis with hydrogen fuel. In this analysis, it was assumed that production by renewable energy sources (solar, wind, biomass) added to sustainable hydroelectric and geothermal sources could reach 40 % by 2050 and the remainder would consist of a combination of fossil and nuclear energy resources. With reliance in New Zealand's desire to emphasise renewable resources by increasing the fraction of renewables to 50 % (65 TWh of the conservative estimate for 130 TWh in 2050), the other 50 % could be 65 TWh from fossil fuels or from nuclear power. On the basis that a 1350 MW nuclear reactor operating at plant factors of about 80 %, the electric energy generated is 10 TWh/year. Thus, fossil fuels for transportation could be entirely eliminated in New Zealand by 2050 with the construction of six to seven such power plants over the next 50 years.

## 7. References

- [1] K. Clapham and A. Tokelove, "Hydrogen Infrastructure for New Zealand", Research Study Report, School of Civil and Environmental Engineering, Unitec Institute of Technology, Auckland, New Zealand, 2001.
- [2] J. Norfolk, "Hydrogen Powered Vehicles; Development to Date", Research Study Report, School of Civil and Environmental Engineering, Unitec Institute of Technology, Auckland, New Zealand, 2001.
- [3] S. Stratton and R. Levet, "Environmental Impacts of Motor Vehicles with Reference to the Introduction of the Hydrogen Fuel Cell to New Zealand", Research Study Report, School of Civil and Environmental Engineering, Unitec Institute of Technology, Auckland, New Zealand, 2001.
- [4] P. Vasisht, "Profile of New Zealand Motor Vehicle Fleet", Research Study Report, School of Civil and Environmental Engineering, Unitec Institute of Technology, Auckland, New Zealand, 2001.
- [5] B. Yardley, "New Zealand Transport Fleet Transition to Hydrogen", Research Study Report, School of Civil and Environmental Engineering, Unitec Institute of Technology, Auckland, New Zealand, 2001.
- [6] P. Kruger, "Electric Power Requirement in the United States for Large-Scale Production of Hydrogen Fuel", *Int'l J. Hydrogen Energy* 25, 1023-1033, 2000
- [7] New Zealand Official Yearbook, 102<sup>nd</sup> (and earlier) Editions, David Bateman, Wellington, New Zealand, 2001.

- [8] Statistics New Zealand, “SNZ – Future Population. Summary of Latest Trends”, <http://stats.govt.nz/domino/>, 2001.
- [9] Land Transport and Safety Authority, “New Zealand Motor Vehicle Registration Statistics”, Palmerston North, NZ, 2000.
- [10] Land Transport and Safety Authority, “New Zealand Travel Survey Report”, <http://www.ltsa.govt.nz>, 2001.
- [11] Ministry of the Environment, “Environmental Performance Indicators Programme: Total Vehicle Kilometres Travelled”, <http://www.environment.govt.nz/transport/vkt/>, 2001
- [12] Ministry of Economic Development, <http://www.med.govt.nz/>, 2001
- [13] Ministry of Economic Development, “New Zealand Energy Data File”, 2000
- [14] Sinclair Knight Merz & Centre for Advanced Engineering, “Electricity Supply and Demand to 2015”, 5<sup>th</sup> Edition, 2000.
- [15] Auckland Regional Council, “Ambient Air Quality: Monitoring Results for the Auckland Region 1964-1995”, Tech.Pub. No.88, 1997.
- [16] Energy Efficiency and Conservation Authority, “National Energy Efficiency and Strategy”, Wellington, NZ, 2001.
- [17] J.P. Blakeley, “New Zealand’s Energy Resources” Proceedings, Chap.13, Integrated Energy Systems-Sustainable Energy Forum Conference, Dunedin, NZ, July 2000.
- [18] B. Arnason and T.I. Sigfusson, “Iceland – a Future Hydrogen Economy”, *Int’l J. Hydrogen Energy* 25, 389-394, 2000.
- [19] A. Poletti, “Nuclear Power is Best Option”, New Zealand Herald, 29 November 2001.
- [20] P. Kruger, “Electric Power Requirement for Large-Scale Production of Hydrogen Fuel for the World Vehicle Fleet”, *Int’l J. Hydrogen Energy* 26, 1137-1147, 2001.

[Back to Contents](#)

==