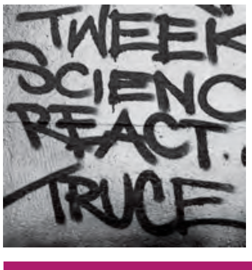
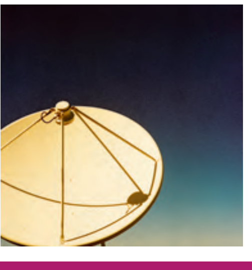
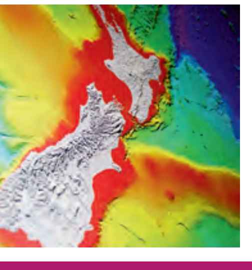
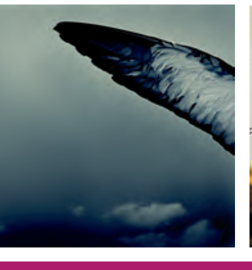
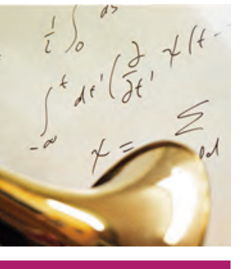
# 2020: Energy Opportunities

## Report of the Energy Panel of The Royal Society of New Zealand

## Book II Appendices

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# 2020: Energy Opportunities
# Report of the Energy Panel of
# The Royal Society of New Zealand
# Book II Appendices
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# TABLE OF CONTENTS

# RECOMMENDATION 1
# OPPORTUNITIES, TARGETS AND STRATEGIES

That Government set aggressive but achievable targets for renewable transport fuels, phase out the use of fossil fuels unless carbon emissions can be securely sequestered and put in place the regulatory and investment policies necessary to ensure fossil fuel free targets are met by 2020.

*"The whole world is now dreading the problems brought about by dependence on oil… The aim is to break dependence on fossil fuels by 2020." - Mona Sahlin, Swedish Minister for Sustainable Development*[1]

I. 1. New Zealand's energy use continues to increase. Our present way of life has been substantially built on energy from fossil fuel, our energy efficiency is not improving and our dependence upon fossil fuels is increasing. Evidence about the risks and costs of climate change continues to accumulate and the physical evidence that human activities are increasing the rate of climate change is certain. The costs of doing nothing will be immense, whereas the costs of mitigation and adaptation will be much less in comparison.

I. 2. Inexpensive and secure energy has been a major source of competitive advantage for our economy. New Zealand has benefited from a hundred years of inexpensive, reliable hydroelectricity and from twenty-five years of inexpensive, reliable Maui gas.

I. 3. We have sufficient cost-effective indigenous resources to return to a renewable energy basis for our economy. We can use our renewable energy sources to achieve certainty of supply for long term energy and business investments, freeing us from the economic insecurity borne of our dependence on fossil fuels, meeting our climate change obligations and helping New Zealand to be among the economic leaders of the twenty-first century.

I. 4. New Zealand has sufficient marginal land and water to grow energy crops and become more than self sufficient in biofuels.

I. 5. We need more renewable generation, new ideas, innovations in markets and new technologies that will allow our twenty-first century electricity and transportation systems to grow and function within economic and environmental constraints.

I. 6. Above all, what New Zealand urgently needs is an energy strategy[2] that provides certainty of supply and builds on our natural advantages in the global carbon market, namely our relatively benign climate and capabilities in agriculture. Furthermore, we need programmes that will allow us to grow new energy-based industries. With increasing global demand for energy security and a cleaner and greener environment, future industries will emerge in this century based around energy and the environment. New Zealand has the opportunity to use an energy strategy to effect economic transformation but must have the resolve to act.

[1] Sahlin, Mona, "Sweden first to break dependence on oil!" in Dagens Nyheter, 01 October 2005 http://www.sweden.gov.se/sb/d/3212/a/51058

[2] As recognised in the recent IEA review "Energy Policies of IEA Countries – New Zealand", 2006

## BACKGROUND TO OPPORTUNITIES, TARGETS AND STRATEGIES

### 1. Renewable Energy Strategy

*Developing a strategic plan to address our energy future presents perhaps the greatest single opportunity before us for radically transforming New Zealand's economy.*

The overarching issues are clear. Indigenous oil and gas resources are limited. Our national energy security is at growing risk from our total dependence on overseas supplies of oil for transport. Our economy is affected by the rising price of oil and our growing current account deficit. The continued use of fossil fuels is accelerating climate change, which will introduce a new layer of costs.

Because energy plays a fundamental role in agricultural production, transport, economic development and social well-being, this challenge at the same time also presents a major opportunity to transform the nation's economy.

The effect of the cost of energy on our current balance of payments cannot be ignored. Any investment in home-grown energy sources that will lead to a reduction of the importation of fossil fuels will create investment opportunities in New Zealand.

New Zealand has a range of renewable energy sources – hydro, geothermal, wind, solar, marine, biomass – and these are important components of any strategic plan that addresses our energy future. New Zealand also has coal but its long term use requires new and unproven carbon capture and storage technology.

Investment from the private sector is critical to any attempt to change our economy. Without a national strategy, the investment sector will remain sceptical to the growth of new industries. The quest to develop renewable sources, and at the same time, to protect our environment is already spawning, world-wide, a new set of emerging industries focused on energy and environmental solutions. A national energy strategy with strong development of renewable resources must also form a blueprint that gives investors the confidence to invest in New Zealand's new business opportunities.

Strategic decisions are in danger of being made on a short-term price basis. These prices are increasingly volatile, with official oil price predictions recently being revised upwards by 300%[3]. This short-term volatility makes long term energy investments risky and leads to increasing energy insecurity; the record prices for oil are leading to sudden increases in costs for industry and the public.

We need energy policies that build on our natural advantages of our relatively benign climate and abilities in agriculture. If we do well, then this will lead to savings but if we ignore the energy opportunity, or if we develop a poor strategic plan, then this will continue to cost us billions annually.

### 2. Renewable Biofuels

*The transport fuel industry consumes 42% of energy used in New Zealand and this alone has major implications for national security. Domestic transport is also responsible for 46% of carbon dioxide emissions[4].The development of renewable sources of transport fuels competes directly against a giant, entrenched global fossil fuels industry which has large economies of scale[5].*

Biofuels are the only current source of low-carbon transport fuels[6]. Across the globe, many nations are responding to the same issues by implementing a range of policies to

[3] MED, "Oil Price Assumptions for Energy Outlook", 2005. http://www.med.govt.nz/templates/Page____10612.aspx

[4] MED, "Energy in Brief", 2006, p8 and p31.

[5] IEA, "Biofuels for Transport – An International Perspective", 2004, discusses economies of scale in biofuels production, p72. http://www.iea.org/textbase/nppdf/free/2004/biofuels2004.pdf

[6] Gielen, D., Unander, F., "Alternative Fuels: An Energy Technology Perspective", IEA/ETO Working Paper, March 2005, http://iea.org/textbase/papers/2005/ETOAltFuels05.pdf

ensure that they develop a domestic biofuel industry. Their policies include fuel standards, biofuel sales mandates, tax support and import restrictions.

Brazil has used "blending mandates, retail distribution requirements, production subsidies, and other measures."[7]. Mandates for blending are used in US, Canada, India, China and many other countries. The EU has several biofuels targets, increasing with time, and several EU countries have biofuels promotion laws.

The US and Canada have substantial tax incentives for biofuels. France, Germany, Spain, the UK and other EU countries have tax exemptions on biofuels. Australia provides cleaner fuels grants as effective tax exemptions and import tariffs, and plans to do so until 2015[8], and has provided substantial research, development, commercialisation and production subsidies.

Many governments are supporting commercialisation and development of biofuels through investment and incentives for investment into biofuels production facilities. Canada has a National Biomass Ethanol Programme to support industry investment in ethanol production and processing. Finland has a government-supported ethanol pilot plant, the Portuguese government has provided finance for a pilot biodiesel plant, and the Spanish government subsidises biofuels plant construction[9].

Brazil now produces fuel from sugar cane at a cost as low as US$25 per barrel[10], a substantial reduction over the last twenty years[11]. Brazil produces 40% of its transport fuel from only 0.6% of its land area. To achieve this, their industry required support for twenty years, but price supports are being phased out and production and trade subsidies have finished[12].

New Zealand could choose to take the path of attempting to import biofuels needs. This would place its energy security at great risk. China has had to suspend blending mandates as sufficient volumes of ethanol could not be obtained on the world market, despite recent prices rises[13]. The US has continued its trade restrictions. It is possible that large international markets for importing and exporting ethanol and other biofuels will not develop because of enormous domestic demand, making domestic production ever more important and production for export ever more profitable for all nations.

We urge the government to consider the potential opportunity, as well as the scale and urgency of the problem. The response should be to set aggressive targets and to introduce policies that will grow a nascent domestic biofuels industry.

## 3. Transport systems

Biofuels alone will not be sufficient to solve our transport system's problems. While New Zealand has the potential to produce sufficient biofuels for our current transport consumption, our transport fuel use continues to grow at 4%[14] per annum, doubling every 18 years.

The transition to a sustainable transport system without high social and economic impact will require careful planning. We also need to plan how to minimize impacts from substantial fuel supply shortages. At present we can only point to potential areas that might

[7] Worldwatch Institute, "Renewables 2005 – Global Status Report", 2005
http://www.worldwatch.org/press/news/2005/11/06/

[8] Australian Taxation Office, "An overview of excise on biodiesel"
http://www.ato.gov.au/businesses/content.asp?doc=/content/52808.htm&page=5&H5

[9] IEA, "Biofuels for Transport – An International Perspective", 2004, pp147-154
http://www.iea.org/textbase/nppdf/free/2004/biofuels2004.pdf

[10] Poppe, M, and Macedo, I., "Sugar solution", in "Our Planet", UNEP, Vol 16, No 4, pp24-27

[11] IEA, "Biofuels for Transport – An International Perspective", 2004, discusses Brazilian costs for biofuels production, p75
http://www.iea.org/textbase/nppdf/free/2004/biofuels2004.pdf

[12] Poppe, M, and Macedo, I., "Sugar solution", in "Our Planet", UNEP, Vol 16, No 4, pp24-27

[13] Worldwatch Institute, "Renewables 2005 – Global Status Report", 2005
http://www.worldwatch.org/press/news/2005/11/06/

[14] IEA, "Energy Policies of IEA Countries – New Zealand", 2006, p101

reduce the cost of the transition. These will include fuel efficient and biofuel-capable vehicles and may include public and low-impact transport. However, the transition will require more than just these marginal improvements.

A cultural shift is required to make our transportation system sustainable. We assume unlimited mobility. The breaking of that assumption can proceed in two ways. Firstly, it can occur through crises as fuel prices and shortages drive short-term behaviour. If that occurs, then pressure for continued unconstrained mobility, at whatever cost, will result in short-term solutions with serious long term consequences. Secondly, it could occur over time as a smooth transition, thanks to forward-thinking policies that assure transport services and efficient and responsive transport systems. Policies that might support this transition might include different incentives for car ownership, expanded public transport, increased electrification of transport, redesign of urban areas or freight systems, workplace support for less private travel, and personal, tradable carbon quotas. We need a major research initiative to investigate such options and ensure effective policy development.

## 4. Zero-carbon electricity

New Zealand is one of a few countries that has the opportunity for a zero-carbon electricity system. We should aim for an electricity system that produces zero carbon emissions in use. The initial steps towards this goal lie in shifting investment to the demand side, with substantial steps to raise our energy efficiency. When a cost-effective balance between investment in better use and current generation of electricity is reached, the next step, unless carbon capture technology meets stringent standards, will be to replace coal and gas-fired generation with expanded renewables – geothermal, wind, and marine.

These actions would return our electricity supply to the security, certainty and continuing low prices that have provided us with a competitive advantage over the last fifty years.

## 5. International Agreements

New Zealand must push for a follow-on agreement to the Kyoto Protocol that will limit climate change by controlling global emissions. New Zealand's emissions are a small fraction of global emissions and our actions alone will not make a difference. However, our bargaining position and our diplomatic strength could come from our record of environmental performance.

As an exporter, New Zealand is penalised by distance from markets. For some goods, such as food exports to overseas consumers, we are at risk from concerns about 'food-miles'. Hence to protect our trade, and our brand, the environmental performance of our energy sector should be exemplary. We can do this at far lower cost than other nations because we already have large renewable supplies and the potential to greatly expand them. We would be irresponsible not to take these opportunities.

## 6. Energy Research

*New Zealand's energy problems must be solved for New Zealanders by New Zealanders.*

Because New Zealand is a small country with a relatively small base in science and technology, there is an attitude in facing large problems that we should be only importers rather than developers of technology. It is commonly held that research can be 'out-sourced' so that others can solve our problems for us.

Where they are available, we should import energy technologies to New Zealand, adapt them to our needs and even export our adaptations. However, this is likely to provide only a small part of our energy solutions.

We cannot afford to ignore the enormous scientific, technical, engineering and social behavioural issues that collectively form the "New Zealand" context. We have the scientific, technological and engineering talent necessary to solve many of our energy problems. We need a strategy to ensure we have the resolve.

# RECOMMENDATION II - RENEWABLE TRANSPORT FUELS BY 2020

> That biofuels be introduced as soon as possible, to provide greater security of transport fuels, with an emphasis on developing local industries for their production.

*"Oil… its volatile price erodes prosperity; its vulnerabilities undermine security; its emissions destabilize climate"*[15]

II. 1. Some 6.3 billion litres of transport fuel are currently consumed annually in New Zealand. This is 3.4 billion litres of petrol and 2.9 billion litres of diesel[16] and representing approximately one third of our annual current account deficit.

II. 2. New Zealand agriculture produces sufficient tallow to produce around 200 million litres of biodiesel annually, equivalent to less than 5% of our diesel fuel consumption[17]. While biofuel production can begin from this source, it cannot make more than a minor contribution to our transport fuel supply.

II. 3. The impact of Kyoto protocol obligations and escalating oil commodity prices have created a worldwide resurgence of interest in both biodiesel and bioethanol production. The International Energy Agency (IEA) projects that biodiesel and bioethanol production is set to rise to 23 billion litres and 120 billion litres respectively by 2020.

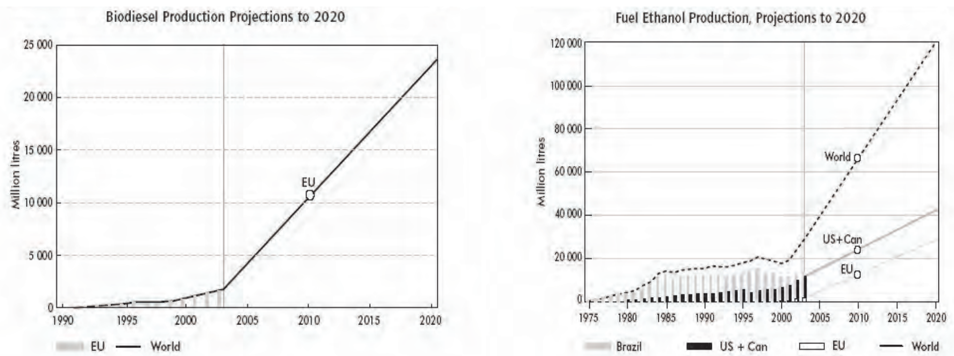


**Figure 1:** IEA projection of biodiesel and bioethanol production to 2020[18].

II. 4. The focus of renewable fuel programmes in the United States, Brazil, Japan, Canada, Southern Asia, and China is largely on bioethanol[19]. International demand for biofuels today exceeds current global global production capacity and so the price of ethanol has risen as many countries seek to replace petrol with bioethanol[20].

II. 5. Even if IEA projections were accurate then there would be sufficient ethanol available for only an E6 blend of ethanol with petrol in the world transport fuel supply. This must mean that there will be long term limitations on the supply of ethanol through the export ethanol market as producers seek to satisfy domestic needs first.

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[15] Rocky Mountain Institute, "Winning the Oil Endgame", 2006-06-08
http://www.oilendgame.com

[16] New Zealand Energy in Brief,
http://www.med.govt.nz/energy/eib

[17] http://www.eeca.govt.nz/eeca-library/renewable-energy/biofuels/fact-sheet/biofuel-fact-sheet-05.pdf

[18] International Energy Agency/OECD, "Biofuels for transport: an international perspective", 2004, p 167 and 169.

[19] International Energy Agency/OECD, "Biofuels for transport: an international perspective", 2004, p 167 and 169.

[20] California Energy Commission:
http://www.energy.ca.gov/gasoline/graphs/ethanol_18-month.html

II. 6. New Zealand's expertise in agriculture and forestry, good growing conditions and small population imply that we could be one of the few countries in the world that can meet its own biofuels requirements.

II. 7. New Zealand has the potential to produce much greater volumes of bioethanol than biodiesel as more extensive feed-stock resources are available.

II. 8. Available technologies for ethanol production are biorefining plant biomass or gas fermentation.

II. 9. Adoption of policies that encourage plant conversion to ethanol and co-products, and total biomass refining will create a value chain from biomass production to processing, distribution and market use.

II. 10. Feedstocks that could make significant contribution to the production of transport ethanol in New Zealand include maize, grasses such as *Miscanthus*, lignocellulosic (woody) feedstocks such as pine, forestry residues, wood processing waste and coppicable woody crops[21].

II. 11. While pine resources are currently large, long term coppicable hardwood feed-stocks offer greater potential, as energy balance, harvesting and biorefining costs are more favourable, and offer a greater range of high value multiple valuable product streams in addition to ethanol.

II. 12. While ethanol is one of these products, ethanol may or may not be the economic driver. Natural lignin has properties that will allow it to compete with other pet-rochemical feedstocks in plastics, resins, paints and adhesives.

II. 13. One million hectares would be sufficient to produce 3-4 billion litres of bioethanol per year and large quantities of other valuable by-products. In the North Island alone there are more than one million hectares of marginal lands suitable for energy farming. In the South Island, there are more than two million hectares[22]. New Zealand has enough land to be more than self-sufficient in biofuels.

II. 14. However, unless new technology is developed to produce or replace diesel, then it will be difficult to produce sufficient biodiesel[23].

II. 15. Gas fermentation technologies could utilise existing pine forestry wastes as feedstock in the gasification process.

II. 16. New Zealand's large potential supplies of renewable electricity could enable the widespread use of hydrogen as an energy carrier. We should to follow international developments in hydrogen technology although its adaptation for widespread use is some time away.

[21] International Energy Agency/OECD,"Biofuels for transport: an international perspective", 2004
DiPardo, J., "Outlook for Biomass Ethanol Production and Demand", Energy Information Administration, US Department of Energy
http://www.eia.doe.gov/oiaf/analysispaper/biomass.html

[22] Includes only land that is currently known to return less than $350 per hectare per year, and excludes dairy and horticulture, native reserves and Department of Conservation land.

[23] Mittelbach, M., "Biodiesel - The Comprehensive Handbook", Graz, 2004

# BACKGROUND TO RENEWABLE TRANSPORT FUELS BY 2020

## 1. Background

A biofuel is any gas or liquid fuel derived from biomass, such as plant material such as wood chips, material from other recently living organisms, such as tallow, or the metabolic by-products of living organisms, such as manure from farm animals[24]. As the carbon in biofuels has been extracted from atmospheric carbon dioxide by growing plants, burning it does not result in a net increase of carbon dioxide in the Earth's atmosphere. Thus biofuels represent a renewable form of energy, unlike other resources such as petroleum and coal.

Biodiesel is produced from two main feedstocks; (i) virgin or recycled animal fats and oil, and (ii) plant oils (soy, canola, palm, corn, rape seed). Triacyl glycerol fats are efficient energy storage molecules in biological systems. These fats can be used instead of petroleum diesel in some robust diesel engines, but more commonly the fats are de-esterified, releasing the fatty acid molecules from the glycerol (which is a useful by-product) and these fatty acids then used in any diesel engine. The combustion qualities of this biodiesel are very good and indistinguishable from petroleum diesel. Furthermore, greater mileage, less particulates and lower sulphur dioxide emissions occur using biodiesel as opposed to petroleum diesel.

Bioethanol is made from plant feedstocks containing sugar, starch or cellulose. The growth of the bioethanol industry over the past two decades has resulted in competition with the food industry for sugar and corn starch feedstocks. Today sugar prices are at a 24-year high; currently 6% of the annual corn production in the United States is diverted to bioethanol production[25].

To be mixed with petroleum, ethanol needs to be anhydrous, adding an energy burden and some difficulties because it is hygroscopic. This is because the water it contains is not miscible with petrol and will separate out causing corrosion and potential blockages in the fuel system. Internal combustion engines can run on hydrous ethanol alone (~96% ethanol, 4% water) and the water contained even adds an advantageous cooling to combustion. In this situation, the water stays mixed with the ethanol. Ethanol has slightly lower energy content than petrol and a different flame speed, meaning vehicles using it need to have adjustments made to their carburation/aspiration (increasing the mass flow accordingly) and ignition timing. This also means that overall consumption is marginally higher than petrol, but efficiency of combustion itself can be higher because the compression ratio can be increased to as much as 15:1 due to ethanol not suffering from pre-ignition problems. Flexible fuel vehicles are able to sense the mixture of ethanol in petrol and adjust combustion conditions accordingly on the fly.

Some difficulties can arise with the compatibility of ethanol with the materials used in fuel systems, though in most modern vehicles does not pose a problem. For New Zealand a difficulty is a reliance on imported used vehicles and reluctance of the manufacturers and importers of those vehicles to certify them for use with ethanol petrol blends beyond E5. Stringent testing of a sample of these vehicles is needed to determine if most of these cars will function well to E20.

Butanol is a four-carbon alcohol and can be used as a renewable fuel. It can be produced in a mixed fermentation of complex polysaccharides by the microorgansim *Clostridium acetobutylicum*, which also produces acetone and ethanol. This so-called acetone-butanol-ethanol fermentation was used on huge scale in the first half of the 20th century as the valuable products were used in many processes and products. It was only surpassed in the 1960's when cheap petrochemical derivatives became competitive.

[24] http://www.eeca.govt.nz/eeca-library/renewable-energy/biofuels/fact-sheet/biofuel-fact-sheet-05.pdf

[25] International Energy Agency/OECD, "Biofuels for transport: an international perspective", 2004, p125 http://www.iea.org/textbase/nppdf/free/2004/biofuels2004.pdf

As a transport fuel butanol can be blended with petrol without drying or used directly in internal combustion engines. It has very similar combustion qualities and energy content to petrol (actually it has a slightly higher octane level) because it is a longer chain molecule than ethanol. It can therefore be used without any adjustment to combustion parameters such as mass flow, timing, and is more compatible with many of the components used in the New Zealand transport fleet and distribution infrastructure. Problems may arise with pollutants from cold starts and a means of avoiding emissions of butanal from cold engines may be necessary.

## 2. The Global Problem

Globally, we consume 1400 billion litres (bnL) of petrol per year[26]. Increasingly, nations are viewing greenhouse gas emissions as the major contributor to global climate change and are seeking to meet their expanding energy needs through "renewable" sources such as biofuels. The only form of solar energy harvesting that can contribute substantially to transportation fuel needs, at costs competitive with fossil fuel, is that captured by photosynthesis and stored in biomass.

The global production of all grade bioethanol for 2005 was estimated to be 46 billion litres. Brazil now obtains a quarter of its ground transportation fuel from ethanol produced by the fermentation of sugar cane sugars. In 2005 this was over 10 billion litres (bnL)[27].

In the United States, approximately 90 corn grain-to-ethanol refineries produce 17 bnL of ethanol annually[28]. The U.S. Energy Policy Act of 2005 targets an increase in production to 28.3 bnL by 2012. The United States currently uses about 530 bnL of ground transportation fuel per year. To replace 30% of that amount with ethanol of equivalent energy content, as proposed recently by the Secretary of Energy, will require about 227 bnL of ethanol.

Of production of more than 30 bnL of bioethanol, Brazil and the United States combined export less than four billion litres. Internal demand and legislation make it unlikely that either country will be a major exporter for more than the next one to two decades[29].

Corn to ethanol faces continuing questions about its energy return and sustainability[30]. However, other feedstocks and conversion routes are much more promising, more suitable to New Zealand conditions and will be the main topic of this section.

Projections of the global increase in biofuels production over the next two decades, combined with the projected demands of the largest producing nations suggests that if most countries adopt targets over this period aimed at replacing significant fossil fuel consumption with biofuels, they will each have to develop a substantial home grown biofuels industry. This understanding has already lead many countries to protect the development of their own biofuels industry with regulations and tariffs to ensure that countries do not merely switch from dependence on importing fossil fuel to dependence on importing ethanol.

[26] www.iea.org, "World Energy Statistics", 2005
http://www.iea.org/w/bookshop/add.aspx?id=181

[27] Poppe, M, and Macedo, I., "Sugar solution", in "Our Planet", UNEP, Vol 16, No 4, pp24-27

[28] http://www.ethanolrfa.org/industry/locations/ and Renewable Fuels Association, "Ethanol Industry Outlook 2006", http://www.ethanolrfa.org/objects/pdf/outlook/outlook_2006.pdf

[29] International Energy Agency/OECD, "Biofuels for transport: an international perspective", 2004
http://www.iea.org/textbase/nppdf/free/2004/biofuels2004.pdf

[30] A snapshot of the debate can be found in the Letters page of Science, 2006, 23rd June, Vol 312, No 5781, pp 1743-1748

## 3. Lignocellulosic feedstocks

Wood is comprised of three principal components: cellulose (chains of glucose), hemicellulose (chains of five carbon sugars such as xylose) and lignin (cross-linked phenolic rings that bind the hemicellulose and cellulose together).

The International Energy Agency now actively promotes woody (lignocellulosic) biomass as the best source of feedstock for the bioethanol industry. This is based on cellulose content, availability of suitable growing land in many temperate geographical latitudes and a lack of competition with food markets. The economic efficiencies of different plant sources vary widely.

The processing of woody biomass from forest trees to produce bioethanol has been investigated for more than thirty years worldwide, and processing technologies are widely available. Their economic efficiencies vary widely depending on the feedstock used. Current technologies utilise a variety of chemical processing systems to disrupt the structure of the wood to remove lignin. These processes expose the cellulose for further processing with cellulase (cellulose degrading) enzymes to convert the cellulose to sugars which can then be readily fermented to ethanol and purified by distillation. Natural lignin and hemicelluloses are not widely used today as feedstock chemicals to compete with the petrochemical industry. By contrast, the pulp and paper industry process uses lignin sulphonates as a low value heat source.

Demonstration plants producing ethanol from straw, stover (the stalks left after corn is harvested), rice straw and sawdust are in use in Norway[31], Sweden[32], Canada[33] and the US[34]. The largest plant produces three million litres per annum from straw. Many new plants are being built[35].

A recent analysis[36] concluded that the United States could increase lignocellulosic biomass production by about 1.3 billion dry tons of biomass each year in addition to present agricultural and forestry production This would produce 500 bnL of fuel ethanol from lignocellulosic biomass, roughly 30% of US transport fuel consumption.

In contrast, New Zealand consumed some 3.4 bnL petrol in 2005[37]. This is equivalent to 120 PJ of energy. To replace this energy content with ethanol would require 5.1 bnL ethanol (energy conversion factor 1.6). New Zealand has introduced E10 legislation allowing sales of blended petrol and is committed to zero transport tax on the sale of ethanol as a transport fuel[38]. However, blended petrol is not yet available to the public. If New Zealand is to commit to the use of biofuels, legislation requiring petrol and diesel distributors to make blended fuels available to customers is needed. Such blends may be initially in the range of E3-E8 for petrol and B3-E5 for diesel to allow for concerns of car manufacturers.

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[31] Orkla Borregaard produces bio-ethanol, lignin and other speciality chemcials from cellulose. http://orkla.com/annualreport/2005/5_6.html

[32] Etek runs a pilot plant in Ornskoldsvik using saw dust. IEA Task 39 Newsletter, Issue 16, March 2006. www.task39.org/_assets/_newsletters/IEAT39-16NA.pdf

[33] In Ottowa, Iogen runs a demonstration plant producing over 3 million litres of ethanol from straw. http://www.iogen.ca/company/about/index.html

[34] In the US, Arkenol runs a demonstration plant producing ethanol from rice-straw. http://www.arkenol.com/Arkenol%20Inc/faq01.html

[35] For example, those by Celunol, Katzen, Xethanol and Bioengineering Resources Inc.

[36] R. D. Perlack et al., Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply (DOE/GO-102005-2135, Oak Ridge National Laboratory, Oak Ridge, TN, 2005). †U.S. DOE, Breaking the Biological Barriers to Cellulosic Ethanol: A Joint Research Agenda (U.S. DOE Office of Science and Office of Energy Efficiency and Renewable Energy, 2006) (available at www.doegenomestolife.org/biofuels/).

[37] www.ecca.govt.nz

[38] http://www.eeca.govt.nz/eeca-library/renewable-energy/biofuels/fact-sheet/biofuel-fact-sheet-05.pdf

Current New Zealand production volumes of these renewable fuels are negligible, and there is very little consumer demand or infrastructural support for their use. Little effort has been made to effect changes to the distribution infrastructure or to inform consumers of alternative fuel options.

### 4. Biodiesel in New Zealand

New Zealand agriculture currently produces sufficient tallow to produce around 200 million litres of diesel annually, approximately 3% of our transport fuels. We should begin with this source, but it will likely be only a minor contribution to our transport fuel supply. It would require a significant commitment to the production of plant oils (soy, canola, palm, corn, rape seed) to provide the feedstock to increase biodiesel production. The European experience is revealing that this is associated with significant production costs. Oils from microalgae offer some potential over terrestrial crops and may provide a route to renewable aviation fuels.

The focus of renewable fuel programmes in the United States, Brazil, Japan, Canada, Southern Asia, and China is largely on bioethanol[39] as more extensive feed-stock resources exist. New Zealand has the potential to produce much greater volumes of bioethanol than biodiesel and this may begin with the use of already existing harvest by-products such as ethanol from whey and forestry waste.

### 5. Biorefining ethanol

The feedstocks that have the potential to make significant contribution to the production of transport ethanol in New Zealand include maize, pine, forestry residues such as slash and sawdust, and coppicable woody plants. The core technologies available for use include biorefining or gas fermentation to ethanol.

Maize could be considered because it is currently grown as an annual crop and the technology for ethanol production from corn is in widespread use in the United States. There is already considerable production of maize that could be expanded in the short-term. On average, some 20,000 hectares of maize will yield 100 million litres of ethanol per year. Some of the waste is convertible into stock food.

Implementation of the most modern growing systems will be needed to avoid nitrate contamination of ground water. Sources of energy will be required for processes such as grinding the maize, heating for fermentation, distillation of the ethanol, and drying of protein-rich co-products.

To produce one billion litres of ethanol per annum from maize would involve around 200,000 hectares of land, representing less than two percent of New Zealand's 12.5 million hectares of dairy, sheep or beef farm land[40]. The disadvantage of maize is the poor energy balance, for every joule of energy consumed in processing the returns are 1.67 joules in the form of bioethanol.

New Zealand has large forest plantations of pine which could be considered as potential biomass feedstocks. However, as a softwood, pine is not particularly suited as feedstock for a biorefining industry. It is more suited to gasification processes.

Bioethanol production using a gas fermentation process is a technology in the early phase of commercialisation. Gas fermentation is the process of converting simple gases, including carbon monoxide, carbon dioxide and hydrogen, into ethanol and will be discussed further below (section II.6). If this technology were available then our pine plantations could be considered a valuable feedstock for this purpose.

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[39] International Energy Agency/OECD, Biofuels for transport: an international perspective (2004), p 167 and 169

[40] http://www.maf.govt.nz/statistics

At least 3.2 million wet tonnes of slash are currently produced annually from NZ plantation forests. Of this, about 2.2 million tonnes could be collected relatively easily, possibly during log harvesting as a cost saving measure. The remainder is from steeper country and would cost more to remove. By 2020-2030, these numbers are expected to double if currently planted land and expanded planting were to continue at a rate of about 20,000 ha per annum[41].

In 2005, 8.8 million wet tonnes of logs produced 3.96 million dry tonnes of sawdust (40% moisture). By 2025 to 2030, this volume is likely to almost double if there is sufficient demand for wood at that time to justify harvesting plantation forests that are already planted[42].

### Coppicable Woody Crops

Hardwood coppicable crops have a more favourable energy balance that maize, for every joule of energy consumed in processing the returns are 11-16 joules in the form of bioethanol, and can grow at least as fast.

A number of factors are likely to dominate their use in biorefining in the future:

- high output to input energy;
- the quality of land used;
- biomass yield per hectare per annum; and
- total biomass biorefining yielding multiple high value products where ethanol may or may not be the driver.

Energy farming returns will depend on oil prices, and below $US45 per barrel are likely to be more economical on poor quality lands using woody plants that grow well on such lands requiring little fertiliser or irrigation.

One coppicable woody plant species worth evaluation is *Salix* or cane willow, grown today in Sweden and Britain for use in co-firing with coal to produce heat. *Salix* grows in most geographic regions of the world and includes several hundred species. *Salix* does not require irrigation and such plants have reported growth rates yielding as much as 25 dry tonnes per hectare per year with a capacity to also grow on marginal soils that might otherwise have limited economic value.

The cost of processing biomass to produce fuel ethanol becomes more attractive when the cost is offset by the sale of other products generated from the lignin and hemicellulose fractions of the same biomass. For a woody plant where 50% of wood is cellulose, with the remaining 50% comprising the lignin and hemicellulose components are potential feedstocks for other products. Kraft or sulphonated lignin, a produce of the pulp and paper industry, is mainly considered to be a low-value source of fuel through burning for heat energy. In contrast, natural lignin is a highly reactive, polymeric raw material with the potential as a chemical feedstock to compete with fossil fuel-derived chemical feedstocks for plastic substitutes, resins, adhesives, paints and films.

Moreover, hemicellulose products such as xylose can be used to produce a non-diabetic food sweetener or xylose could be converted to ethanol as yeast strains engineered to ferment C5 sugars to ethanol are now available[43].

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[41] http://www.maf.govt.nz/statistics/primaryindustries/forestry/forest-resources/national-exotic-forest-2005/10-summaries-table4.htm

[42] www.maf.govt.nz/statistics/primaryindustries/forestry/forest-resources/wood-supply-forecasts-2000/index.htm

[43] Current Opinion in Biotech, 2006, volume 17, pp320-326

### Competition for land use

A commonly expressed concern is that New Zealand could only develop an energy farming industry by competing for land with existing agricultural industries. We have undertaken a land use analysis using the woody coppicable crop such as *Salix* and the following parameters:

- land from which current net returns from their current land use option is less than $350 per annum per hectare;
- current estimates of lignocellulosic productivity (16 dry tonnes per hectare) and potential for conversion to ethanol (300 litres per dry tonne) suggest that around 70,000 hectares of plantation land would be required to provide biomass and generate ethanol sufficient to satisfy an E10 mandate for ethanol in blended fuels, and some one million hectares to replace petrol with ethanol at current levels of consumption; and
- use of a geothermal source of heat energy for processing has the potential to significantly reduce biorefining costs. We have focused on land use around three geothermal sites – Mokai, Kawerau and Ngawha Springs.

Current case studies indicate that much dry stock grazing for sheep and beef husbandry generates an income of less than $250 per hectare per annum. This figure is net with respect to all the farmer's costs. This figure was arrived at using information from two sources. First, an independent report on earnings made by farmers, undertaking dry stock farming within the Lake Taupo catchment and second, through published figures detailing returns from country farmers using the land for sheep and beef grazing purposes[44]. This information indicated that most farms average a return after all costs paid of $180-$230 per hectare per year. Some achieve $250-$280 per hectare per year but very few achieved returns of $300 or more per hectare per year.

A geographic information system mapping project was undertaken by AgriQuality to find all land currently idle or in "lower value" land uses through using the Land Cover Database 2 dataset and the AgriQuality's AgriBase™ national spatial farm database. The land sought and identified was less than 1000m in elevation, less than 15 degrees of slope to allow for mechanized harvesting and excluded land known to be committed to dairy and horticultural use, DOC land and native forests.

The preliminary findings indicated that over 8 million hectares of land fell within the defined parameters and as such are suitable for energy farming (Table 1; Figure 2A). The South Island has more suitable land than the North Island (Table 1; Figure 3). Significantly, use of MAF farm monitoring figures (2003 data) identified the subset of land, totaling some 1.4 million hectares in the North Island and 2.6 million hectares in the South Island (Table 1) returning $350 per hectare per year or less (Figure 2B,3). This land included land currently in use for plantation forestry. The majority of identified land was in the central North Island and in the east of the South Island. A significant proportion of the land in the North Island is currently committed to pine plantation forestry (Figure 2C). We have included pine because it may well be a feedstock for gas to ethanol technology (see below).

If the Mokai field, 30 km north of Lake Taupo, were selected as a point reference, then within 100km of this point, there is 1 million hectares of land suitable for growth of a woody biomass crop such as *Salix* (Table 1; Figure 2D). A subset of this land totalling some 640,000 hectares is currently yielding a net return of $350 per hectare per year or less (Table 1; Figure 2E). Significantly, some 78,000 hectares of suitable land lies within the Lake Taupo catchment itself. Taking into account a current commitment to pine forestry within the Taupo catchment of some 53,000 hectares, there remains some 24,000 hectares deemed suitable for energy crop use. If this land alone was committed to biomass and bioethanol production then approximately 100 million litres per annum of ethanol would be produced. This level would be sufficient to support an E3 mandate for ethanol

[44] Country-Wide vol. 28, Northern Edition, May, 2006

in blended fuel. If all marginal lands within 100 km of the Mokai field were committed to bioethanol production then a total of 183,000 hectares of land would produce sufficient bioethanol to support an E23 mandate without impacting on land currently committed to pine forestry.

While we have focused on land around geothermal fields, of course other sources of heat energy can and will be used in biorefining but it is clear that there is sufficient 'marginal land' to consider for energy farming.

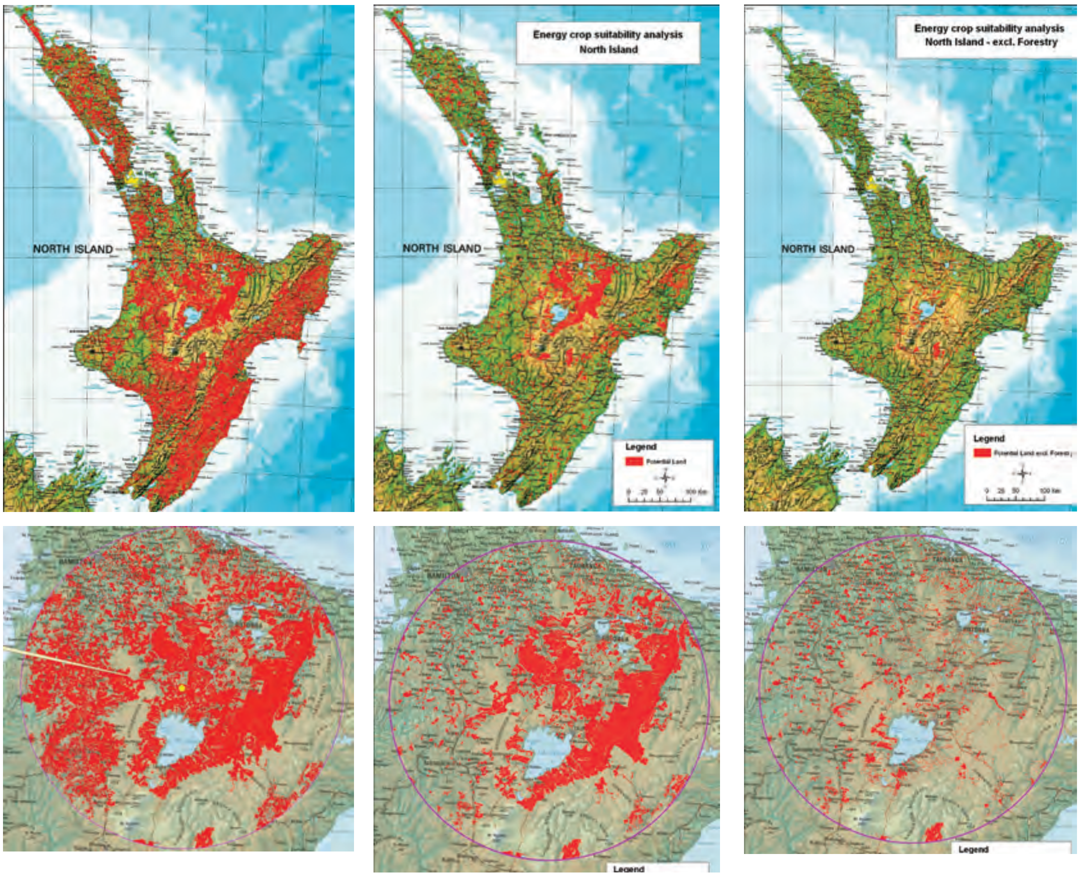


**Figure 2:** Land potentially suitable for energy farming within the North Island shown in red[45].
Analysis of geographic information system databases was performed to identify land (red) less than 1000m in elevation, less than 15 degrees of slope and excluded lands held in the Department of Conservation estate and land committed to dairying and horticultural use.
A, Land identified as suitable for energy crop farming within the North Island;
B, The subset of land within the North Island known to return less than $350 per hectare per year – 1.4 million hectares;
C, The subset of land within the North Island known to return less than $350 per hectare per year and excluding land known to be committed to pine plantation forestry;
D, Land identified as suitable for energy crop farming within 100km of the Mokai geothermal field;
E, The subset of land within 100km of the Mokai geothermal field known to return less than $350 per hectare per year;
F, The subset of land within 100km of the Mokai geothermal field known to return less than $350 per hectare per year and excluding land known to be committed to pine plantation forestry;

45 The source for these numbers was AgriQuality's AgriBase™ national spatial farm database.

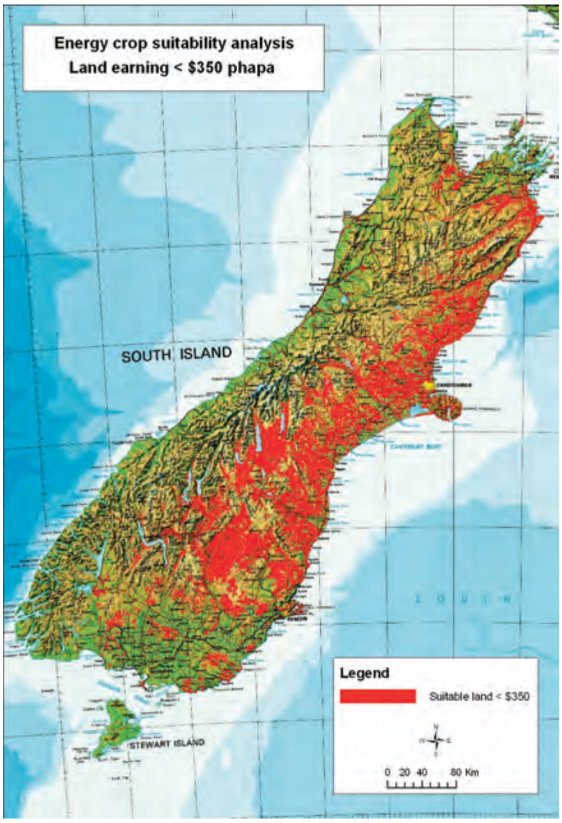


**Figure 3:** Land potentially suitable for energy farming within the South Island shown in red – 2.6 million hectares[46]. Analysis of geographic information system databases was performed to identify land (red) known to return less than $350 per hectare per year, less than 1000m in elevation, less than 15 degrees of slope and excluded lands held in the Department of Conservation estate and land committed to dairying and horticultural use.

**Table 1** Land Suitable for Energy Farming With Access to Geothermal Steam.(Hectares)

| | Suitable for *Salix*[47] | …and EBIT less than $350 p.a.[48] | …and excluding pine forestry[49] |
|---|---|---|---|
| North Island | 4,060,000 | 1,442,000 | 587,500 |
| South Island | 4,356,000 | 2,629,000 | 2,525,00 |
| Lake Taupo catchment | 107,000 | 77,810 | 24,458 |
| Within 100 km Mokai | 1,086,900 | 641,612 | 183,412 |
| Within 100 km Kawerau | 716,900 | 495,127 | 100,336 |
| Within 100 km Ngawha | 375,500 | 153,250 | 60,034 |

## 6. Gas Fermentation

Gas fermentation is the process of converting simple gases, including carbon monoxide, carbon dioxide and hydrogen, into ethanol. Catalytic processes for the conversion of gases to fuels have been known for several decades, but have not been widely commercialized, because only highly pure gas streams can be used to avoid poisoning the catalysts.

[46] The source for these numbers was AgriQuality's AgriBase™ national spatial farm database.

[47] Land identified less than 1000m in elevation, less than 15° of slope, land parcels areas less than 1 hectare in size excluded, excluding Dept. of Conservation estate and high returning land use including dairy and horticulture.

[48] The subset of land indicated as suitable for Salix but known from MAF farm monitoring (2003 figures) to return $350 per hectare per year or less.

[49] The subset of land indicated as suitable for Salix and returning $350 per hectare per year or less and excluding land use currently committed to pine forest plantations
The source for these numbers was Dr Robert Sanson, AgriQuality Limited

Alternatively, biological catalytic pathways found in bacteria can be used to convert these gases to ethanol and are tolerant to impurities in gas streams. A parallel approach can also be made for the use of algal hydrogenase for hydrogen production (see fuels from algae in section II.8).

Gas fermentation can be achieved using a particular genera of bacteria which have the ability to derive all their carbon and energy requirements solely from carbon monoxide, or from carbon dioxide and hydrogen sourced from the breakdown of the starting material. These so-called gas-to-ethanol bacteria utilise these gases, and following a period of growth, can continuously convert these gases to ethanol.

Gas-to-ethanol bacteria require some minerals and vitamins for optimum productivity, but remarkably, do not require added sugars. This means that the process is inherently cheaper than traditional yeast fermentations such as beer and wine production.

The process yields 200 to 300 litres of ethanol per tonne of gases derived from heavy industries or from gasified biomass. Higher rates, around 600 litres per tonne, occur using some other feedstocks such as gasified used tyres or hydrocarbons. BRI Energy appears close to commercialising the first gas-to-ethanol plants in the US[50].

Coupled gasification and fermentation is the process of converting waste into simple gases, primarily carbon monoxide, carbon dioxide and hydrogen, and using these gases as feedstocks for the ethanol bio-conversion process. Many types of waste resources that are rich in carbon are suited to this process including non-renewable resources such as coal, natural gas, refinery tars and waste oils, and, importantly, renewable sources such as waste biomass.

Waste biomass is rich in carbon and can be found in municipal solid waste, sewage sludge, plastics, used tyres, agricultural residues, forestry and other wood wastes. In New Zealand, and indeed, world-wide, this is a vast source of unused or renewable energy.

The process of gasification is a critical step in the use of solid wastes such as biomass and municipal waste. Until recently the large-scale commercial application of gasification has been restricted by economic rather than technical issues. This is because previously the primary products from gasification were electricity or heat, and the low value of these products in today's market has been insufficient to justify the capital and operating costs. However, if gasification is coupled with the production of a higher value liquid fuel as well as electricity or heat, the combination is a viable alternative energy technology.

## 7. A Hydrogen Economy

### Non-fossil fuel sources of hydrogen

The transition to a hydrogen economy as a clean energy source, though attractive in many ways, faces serious stumbling blocks related to the generation, storage and distribution of hydrogen. Presently most hydrogen is produced from petroleum via steam reformation negating any non-fossil environmental advantages as carbon dioxide is released during this process. This is also true if it is produced from lignite coal. Electrolysis is another route to hydrogen generation but similarly, if there is to be any carbon gain, the energy to drive the process must come from renewable energy sources such as solar, geothermal heat or wind and marine electricity.

Although per unit molecule hydrogen has a high energy density, the physical properties of hydrogen means that even as a highly compressed gas its energy density is low compared with traditional fuels. The energy and apparatus required for cryo-storage will probably limit this approach in transport applications. Other technologies such as storage in metal hydrides or nano-matrices are promising and continued R&D efforts are needed.

[50] United States Senate Committee on Energy & Natural Resources, "Full Committee Hearing- Coal Gasification Monday, May 1, 2006": http://energy.senate.gov/public/index.cfm?FuseAction=Hearings.Testimony&Hearing_ID=1548&Witness_ID=4374

An alternative approach is to use hydrogen derived from biological process biomass such as bio-ethanol. While direct use of bio-ethanol for combustion engines is very attractive because as a liquid it can be handled with traditional infrastructure (Route 1, below) a major disadvantage presently of blending ethanol with petroleum is the fact that the ethanol has to be dry which requires extra energy input (section II.1). Another economically promising route (Route 2, below) to using bio-ethanol, is via its conversion to hydrogen for use in fuel cells for power generation, where water present is actually required. This offers greater efficiency, cleaner devices and further flexibility. In the longer term, hydrogen could factor in many of our energy systems both transport and non-transport.

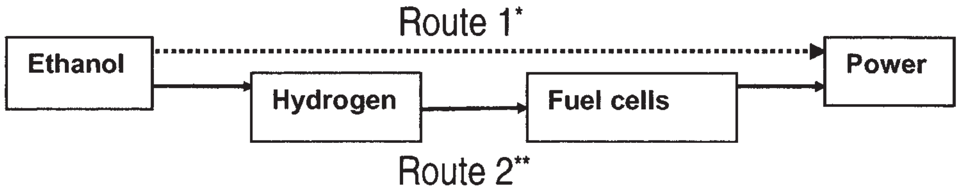


**Figure 4:** Routes from ethanol to power generation
*: current average internal combustion engines is approximately 32% and continues to improve.
**: fuel cell efficiency can be much higher than this depending on the use of surplus heat.

The basic research challenges and solutions lie in hydrogen production, hydrogen storage and the development of fuel cells.

The catalytic production of hydrogen from renewable sources such as ethanol is one promising alternatives for New Zealand. This could combine with fuel cells for production of electricity. Ethanol can also be used directly in fuel cells without needing to be dewatered. Combined with carbon capture and storage, this could allow the production of electricity from ethanol without carbon emission.

However, ethanol is also a convenient energy carrier as a liquid fuel, so it may be more feasible to use ethanol directly, rather than using it as a feedstock in the production of hydrogen. The production of hydrogen can also be achieved by water splitting using sun light and semiconductors but efficiencies are currently very low.

## 8. Fuels from Algae

Biofuels derived from microalgae are also a promising source of renewable energy. Some fossil fuels themselves are a legacy of prehistoric algal photosynthesis, and it is the release of ancient carbon trapped during this period in a comparatively short time, since the industrial revolution, which has been the main anthropogenic influence in the rise in global carbon dioxide levels and the ensuing environmental damage.

Algal photosynthesis is approximately three times more efficient than in terrestrial plants. Thus algae are better at fixing atmospheric carbon dioxide. In microalgae this is due to several factors. As most are single celled organisms, they store starch intra-cellularly, which means the algae do not have to consume ATP, the cellular energy intermediate, to transport glucose. Additionally, other metabolic differences reflecting, in general terms, that microalgae are similar to higher plants in many respects (many are eukaryotic) yet they have a very flexible metabolic repertoire. The ability to be able to carry out mixed fermentative pathways as needed, is similar to many prokaryote microorganisms and microalgae are able to make the most of both worlds. For these and other reasons, the production of oil per unit area of land may be thirty times higher than terrestrial oilseed crops[51].

[51] Sheehan, J., Dunahay, T., Benemann, J., Roessler, P., "A look back at the US Department of Energy's Aquatic Species Program – Biodiesel from Algae", NREL closeout report, 1998 www1.eere.energy.gov/biomass/ pdfs/biodiesel_from_algae.pdf

Photosynthetic light-harvesting by plants is in the order of 95% efficient. Subsequent steps are less efficient and one approach to this problem is reducing the size of the light-harvesting complexes so that less energy is dissipated as heat[52]. This represents one of the many contributions that R&D can have on utilising algal-derived energy conversion for producing fossil-free biofuels. Basic research in these problems can also contribute to synthetic light-harvesting technologies.

Many microalgae store their captured energy as oils, which can be easily extracted and converted to bio-diesel. Pyrolysis of microalgal biomass can also yield useful products including energy intermediates. Many species are 30-50% (dry weight) oil at the end of their life-cycle and it is claimed that some remarkable species are up to 80% oil.

Algal polysaccharides and starch can also be used to produce ethanol via traditional fermentative technologies once the long chain sugars are cleaved to glucose using enzymes similar to those being developed for woody feedstocks for this process. These polysaccharides can also be used in gas-to-ethanol gasification. Marine macroalgae (seaweeds) are very high in polysaccharide content and some grow at outstanding rates. The brown seaweed *Macrocystis* has been recorded at growing up to 1 meter per day. Marine macroalgae also have the advantage that they can be grown offshore circumventing the perceived problem of biomass-based fuels using arable land (section II.5), though there is an energy loss, to some degree, to dry the seaweed depending on how it is to be used partially countering this.

Many microalgae and cyanobacteria are also able to produce hydrogen as a by-product of anaerobic metabolism. Algal hydrogenase is up-regulated in the absence of oxygen to use the reduction of protons to hydrogen gas as an electron sink. The hydrogenase catalytic active center could possibly represent a biological alternative to platinum used in fuel cells[53]. The rarity of platinum is a major reason fuel cells are too expensive for wide scale deployment.

[52] Polle, J.E.W., Kanakagiri, S.,Jin, E.S., Masuda, T., Melis, A., "Truncated chlorophyll antenna size of the photosystems--a practical method to improve microalgal productivity and hydrogen production in mass culture". International Journal of Hydrogen Energy, 2002, vol 27, no. 11-12, pp. 1257-1264

[53] Darensbourg, M.Y., Synthetic chemistry: making a natural fuel cell. Nature, 2005, vol 433, no 7026, pp. 589-91

# RECOMMENDATION III
# SUSTAINABLE TRANSPORT SYSTEMS

That the transport fleet vehicle composition be modified over time to enable the more widespread uptake of renewable fuel use and that transport systems be modified to become sustainable.

III. 1. A transition to a renewable fuel future will require measures to increase the efficiency and flexibility of our transport system. The high price of oil[54] is already raising demand for smaller, more fuel efficient vehicles[55] and for public transport[56]. These high prices are set to continue to increase and to worsen as the full costs of climate change become clearer. With constrained supplies of fuel, whether from oil or biofuels, efficiency will be the key to providing greater levels of productivity and minimising the risk from price and supply shocks.

III. 2. To improve fuel efficiency and flexibility New Zealand needs to introduce acceptable and effective long term strategies taking into account existing vehicle fleets, urban design, transition to biofuels, the long replacement cycle of the transport system and the possibility of sudden fossil fuel supply constraints.

III. 3. Numerous policy tools have been tested internationally for raising the fuel efficiency of vehicles and transport systems. These include vehicle fuel efficiency labeling, emissions testing, insurance-per-mile initiatives, and fiscal or tax incentives for vehicle ownership and fleet standards. Substantial operational research is needed to understand which of these tools will work effectively in New Zealand.

III. 4. Biofuel use is currently severely constrained because the majority of vehicle imports are not warranted for more than 3% biofuel. It would cost relatively little to require all new vehicles to be compatible with higher percentage of biofuels and little more, potentially only a few hundred dollars per vehicle, to convert imported second-hand vehicles to handle higher percentage bioethanol blends.

III. 5. Hybrid vehicles are expensive and are mainly beneficial in urban driving, where other transport modes may be more relevant. The financial costs of supporting these vehicles may be better put towards supporting more accessible transportation modes. Plug-in hybrids are even more expensive and may never compete, financially or environmentally, with biofuel-powered vehicles. Hybrids have a clear advantage in purely urban uses, such as buses, taxis or light rail.

III. 6. The twenty-first century may see an adaptation to a new type of transportation system. Rather than providing on-demand mobility based on unconstrained fuel and emissions, future systems could be based on organising better planned access to services and markets. Advances in information systems, urban design, freight organisation and integration, and economic instruments will be the key elements of adaptation to a renewable energy transportation system.

[54] MED, "Oil Price Assumptions for Energy Outlook", 2005. This report predicted $60/bbl in November 2005. Since then the NYMEX prices have been consistently above that level, peaking at $75/bbl in May with futures markets predicting little decrease. http://www.med.govt.nz/templates/Page____10612.aspx

[55] Dominion Post, "Car sales slump as fuel price soars", 04 May 2006 http://www.stuff.co.nz/stuff/0,2106,3656619a30,00.html

[56] Dominion Post, "Rising petrol costs boost bike sales", 01 May 2006 http://www.stuff.co.nz/stuff/0,2106,3653334a11,00.html

III. 7. International constraints on oil production pose high near-term risks in the form of local and national fuel shortages and fuel price increases that exceed many customers' ability to pay. Shortages could cause price shocks, inflation, loss of transport services with consequential commercial, economic and social effects.

III. 8. Current mitigation strategies only deal with up to 7% supply shortfall[57], but the probability of shortages far above this level occurring within a 10-15 year time frame is high. Strategies for dealing with larger shortages should be a high priority for multidisciplinary research.

III. 9. Managing the transition to renewable energy transportation will require a visionary and multidisciplinary approach to policies, science, engineering, and planning.

[57] MED, "Oil Demand Restraint Options for New Zealand: Planning for Emergencies", 2005 http://www.med.govt.nz/templates/ContentTopicSummary____15103.aspx

# BACKGROUND TO SUSTAINABLE TRANSPORTATION SYSTEMS

## 1. Transportation is a Complex System

Different sectors and individual users have different purposes for their transportation activities. They also have different patterns of use and vastly different amounts of cargo. The number of trips, the frequency of travel and how it is done is called the "Travel Demand", and it is highly influenced by geographic locations and urban forms as well as lifestyle, infrastructure, travel mode options, and the economic substructure (e.g. location of retail, commercial, education, and industrial destinations). The travel demand is interrelated with every other activity sector in our society. Economic, health and cultural activities nearly all depend on people leaving their dwelling place and moving to another location at least once each day.

Private sector travel provides access to work and education, health care, entertainment and community activities, and to access food and other goods. About one third of private sector travel demand has regular and repeated patterns which can be served by fixed-route transportation systems.

Commercial sector travel is used to transport goods and services to customers, and to carry out business activities. Many delivery routes have regular patterns and routes, but due to the amount of cargo being moved and the varied delivery pattern in urban areas, are not currently served by public transport.

Freight sector transport provides the link between producers and consumers by moving goods over long distances. This sector used to be served by rail systems, but currently relies on trucks. The main factor for this change from rail to trucks has been the "just in time" shipping system.

Public sector transport provides removal of waste, and delivery of public services and maintenance. The mode alternatives are similar to the commercial sector.

Transportation infrastructure represents public capital investment to facilitate un-constrained mobility by private individuals and businesses. Infrastructure includes parking lots, rail lines, roads, lights, drainage, and signage.

Public transportation services are often privately operated, publicly underwritten systems involving infrastructure and vehicles, such as air travel and rail, whereas private transportation is accomplished by individually owned vehicles operated on public infrastructure.

## 2. National and Local Transport Policy

Although discussion of transportation policy usually focuses on commuter traffic in urban areas, the transportation system which we use for nearly every facet of our social and business activities is multifarious and more complicated than any other energy consuming system.

The existing policy and planning instruments are aimed at ensuring mobility. Mobility is considered to be the basis for individual participation in economic activities and movement of goods and services. In the 20$^{th}$ Century, mobility was continually increased through public investment in new rail and roads, and private investment in vehicles. On-going expenditures are needed to maintain the infrastructure, police and regulate use of the roads, and deal with injuries and damage. The instruments used to increase and ensure mobility have historically been fuel and vehicle taxes as well as allocation of other non-transport revenues.

Urban areas have invested in public transport for several reasons. Low income people and individuals who are not qualified or able to drive vehicles cannot participate in the economy and community (e.g. going to school) without transportation. Public transport is seen as a service for this segment of society. Public transport is also seen as a means to improve mobility on congested routes by transferring some vehicle transport to a different mode, bus or commuter train.

Modern policy instruments which have been developed overseas include road and congestion pricing. Road pricing is a policy aimed at generating the extra funds for construction by public-private partnerships for investment, with future revenues generated by tolls on users.

Congestion pricing is aimed at improving mobility by reducing the number of vehicles on congested roads, particularly in urban centres. London, Singapore, and other cities have reduced travel times in inner cities through strict congestion pricing and access limitations. These cities have numerous alternative transport options available.

## 3. International Initiatives in Sustainable Transportation

Internationally, organizations have emerged over the past few years to work on the issue of sustainable transportation. Some focus on the issue of peak oil, others on improving quality of life through urban form. The range of ideas and research findings, and in particular, experiences and demonstration projects should be examined for relevance to the New Zealand national strategy to achieve renewable energy transportation.

## 4. Risks and Issues

The most urgent risks to the present transportation system are:

- Fuel shortage
- Fuel price escalation
- Fossil $CO_2$ atmospheric emissions

These key risks and issues have numerous follow-on impacts that are inferred from previous shortage events. However there is no historical precedence for the situation which now needs strategic planning. The issues are complex.

The three key issues represent product failures. People buy cars, businesses buy trucks. They then purchase low-cost fuel and drive on roads financed by the government. The emissions from normal operation of these vehicles using this fuel are causing negative environmental changes. The products work to provide transportation of goods and services. However, the products will not work if fuel supply is disrupted.

There has always been, and will always be a market for transport services that move goods to market and move people to activities. The current transport product is designed in the context of abundant, low cost fossil fuel. The question now is what products will provide transportation services in the 21$^{st}$ Century, and what businesses will provide them to customers?

It is important to understand that the massive investment in roads and materials for vehicles is not independent of low-cost fossil fuel. In addition, the economic activity and wealth used to purchase fossil fuel transport products are generated by fossil fuel use (e.g. tourism, agriculture, export of goods).

A substitute fuel may come from biomass, but globally supplies will be constrained by lack of land and water. A substitute fuel may come from coal or gas, if sequestration technologies can be developed and proven secure, but at a much higher price than current fuels. Hence the transport system will be changed by the loss of cheap fossil fuels.

Substitute modes such as mass transport or electric rail for urban commuters should improve security and emissions. However, freight and international air travel are still at risk from fossil fuel disruptions.

Vehicle technology substitution to higher efficiency or different fuel platforms should reduce risks from fossil fuel disruptions, but if high fuel prices and climate change erode wealth and economic viability, then our ability to replace our vehicle fleet may be very constrained.

Market forces will and are driving moves to provide new fuels and technologies as fuel prices rise. However, this discounts the long term future, ignores social costs of high fuel prices, and leads to disruptive responses to crises that would be better served by a forward-looking government providing long term leadership.

The risk to the entire transportation system and all of the activity which it supports is highly complex. Simple, one-dimensional solutions will not be sufficient.

## 5. Risk Mitigation

The immediate risk of failure of the transport system for all sectors is fuel shortage. Policy and fuel supply management systems must be developed in the near term to distribute constrained fuel supply in a way that avoids the "fuel crisis" failure mode. The government is aware that its response to fuel shortage is not prepared. Fuel suppliers and consumers do not want rationing. Thus, the top priority in strategic policy must be to develop, in concert with fuel supply companies, a fuel supply management system that will distribute available fuel to optimize economic activity and wellbeing.

## 6. Solution

In the long term, New Zealand's transportation system will change and adapt. Companies that can supply transportation solutions in the climate of curtailed fossil fuel use will flourish. Urban and rural landscapes will undergo re-organization and integration. Populations will shift and may locally increase or decrease depending on availability of resources and transportation. A new 21$^{st}$ Century transportation system will evolve which uses renewable fuel. It will be different from the fossil fuel system of the 20$^{th}$ Century. The transport vehicles, infrastructure, and energy supply will be designed and built to provide desirable transport services and goods movement at a price that customers are willing and able to pay.

# RECOMMENDATION IV – A ZERO-CARBON ELECTRICITY SYSTEM

That our electricity sector should make the transition to renewable supply by 2020. Further fossil fuel development must incorporate a commitment to zero carbon emissions. Electricity markets and systems must deliver a balance between supply and demand investments.

IV. 1. New Zealand is an energy-rich country underpinned by large-scale hydro generation, in transition to a more diverse supply portfolio, which will continue to involve fossil fuels for the short term. However our proportionate use of renewable electricity has fallen from 81% in 1990 to 75% in 2004[58]. We need to focus our efforts on growing non-or-low carbon-emitting electricity generation and to make serious efforts to contain emissions from electricity production.

IV. 2. Renewable electricity costs are not directly tied to volatile oil and gas prices and generate energy with zero carbon emissions. Indeed, the cost of renewable electricity continues to decrease, with the cost of producing electricity from wind energy falling by over 80% over the last twenty years[59]. Fossil fuel prices are tied to oil prices which are increasingly volatile[60]. For biomass-based fuels, we will have much greater control over the feedstock cost and therefore be less subject to the fluctuations of oil and gas on world markets.

IV. 3. At present, wind and geothermal generation are growing rapidly but not as fast as oil and gas[61]. Wind, geothermal and hydro have great potential but are currently limited by resource consent application difficulties. Regulatory barriers apply to these sources where, under the current RMA, passing the control of such national assets down to local authorities has constrained their optimal development. These barriers should be addressed by supportive amendments to the Resource Management Act. However, any increase in electricity generation will have environmental costs, locally for renewables and globally for non-renewables. At present, our demand growth requires an extra 100 MW of thermal generation or 220 MW of intermittent renewable generation per year. Efficiency and demand side approaches should be the first step.

IV. 4. Currently, 600 MW of new generation from renewables should be in operation by 2008. Wind power is cost-competitive and growing rapidly. In the long term, wind generation may be limited to 35% of peak power by the difficulty of integrating a fluctuating supply with the grid[62]. However, by 2020 wind could provide another 2,000 MW[63].

[58] MED “New Zealand Energy in Brief”, 2006, March
http://www.med.govt.nz/upload/32800/2006.pdf

[59] NREL Energy Analysis Office, “Renewable Energy Cost Trends”, 2002
http://www.nrel.govt/analysis/docs/cost_curves_2002.ppt
Electric Power Research Institute, “Economic Assessment Methodology for Offshore Wave Power Plants”, report E21 EPRI WP – US – OO2, November 2004
http://www.epri.com/attachments/297213_002_Rev_4_Econ_Methodology_RB_12-18-04.pdf

[60] Coal retail prices have doubled since 1985. IEA, “Energy prices and taxes”, 2006, New Zealand, Table 4

[61] IEA ” Energy Policies of IEA Countries – New Zealand”, 2006, p159

[62] MED, “Wind Energy Integration in New Zealand – Final Report”, 2005
http://www.med.govt.nz/templates/MultipageDocumentTOC____4317.aspx

[63] Electricity Commission, “Scenarios for the Wind Generation Investigation Project: December 2005

IV. 5. Geothermal generation provides renewable power without intermittency or weather-dependence. It provides base-load power operating with over 90% load factor. In the long term, could provide more than 600 MW[64], possibly 1,300 MW[65] Geothermal generation costs are competitive with coal and gas and currently less than either. Geothermal costs are even lower when compared with international fossil fuel prices such as for imported coal. Reinjection of working fluid reduces subsidence and heavy metal discharge and should be included in all developments.

IV. 6. If New Zealand exploited its enormous potential in lower temperature geothermal resources, then a significantly greater proportion of New Zealand's electricity needs could be met from renewables. It has been estimated that the potential extractable energy at lower temperatures could at least double New Zealand's geothermal energy supply[66].

IV. 7. There is the potential for further increases in hydro-generation on a range of scales, from small to large[67].

IV. 8. Marine generation is becoming commercially available. Many different marine generation technologies are being trialled on a commercial basis. Costs are dropping just as they did for wind generation, through design optimisation and economies of scale. For example, the UK is investing NZ$150 million in a Marine Renewables Deployment Fund[68]. This support should rapidly reduce the cost of marine generation and is expected to provide a net saving overall[69]. The long term price of marine-generated electricity may be equivalent to or lower than the cost of wind-generated electricity[70].

IV. 9. Marine generation in Scotland may provide 1300 MW by 2020[71]. New Zealand's potential supply of wave and tidal stream resources are reportedly 'tremendous'[72] and probably better than Scotland's but the resources are not well characterised yet. New Zealand's resources should work well with other renewables, providing more energy in winter, and we have large resources close to major users.

IV. 10. Direct generation of electricity from photovoltaic cells (solar panels) remains too expensive for bulk applications and we expect this to still be the case by 2020. However, costs continue to fall and this will enable photovoltaic cells to be used in increasing numbers of niche markets. The direct use of heat from the sun, through solar water heating and passive space heating, is competitive and should be encouraged as a means to reduce electricity use for heating.

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[64] Geothermal Association, "Geothermal Energy: New Zealand's most reliable sustainable energy resource", February 2006

[65] MED, "Existing and Potential Geothermal Resource for Electricity Generation", December 2004

[66] Reyes A.G. 2006. "Geothermal energy from abandoned oil and gas wells- a reconnaissance study", GNS Science Report 2006/06

[67] East Harbour Management Services, "Identification of Potential Hydroelectric Resources", July 2004

[68] http://www.dti.gov.uk/energy/sources/renewables/business-investment/funding/marine/page19419.html

[69] The Carbon Trust, "Future Marine Energy: Results of the Marine Energy Challenge: Cost competitiveness and growth of wave and tidal stream energy", 2006 http://www.carbontrust.co.uk/technology/technologyaccelerator/marine_energy.htm

[70] Electric Power Research Institute, "Economic Assessment Methodology for Offshore Wave Power Plants", report E21 EPRI WP – US – OO2, November 2004 http://www.epri.com/attachments/297213_002_Rev_4_Econ_Methodology_RB_12-18-04.pdf

[71] Marine Energy Group, "Harnessing Scotland's Marine Energy Potential", 2004 http://www.scotland.gov.uk/Publications/2004/08/19742/41047

[72] NIWA, "Ocean bounty: energy from waves and tides", in Water & Atmosphere, 2005, volume 13, number 4, pp16-17.

IV. 11. Given our abundant renewable resources, the high costs of nuclear power, the large size of nuclear generating plants, our lack of experience with the technology and the risks associated with nuclear waste, nuclear power is not a viable option for New Zealand.

IV. 12. Our cost-effective renewable resources are capable of meeting our electricity needs for the future.

IV. 13. Distributed generation is low risk, provides resilience, especially for rural communities, allows for incremental investment and reduces grid dependence and load. Combined use of heat and power can reduce overall emissions[73] and raise overall efficiency. Microgeneration should be encouraged if grid expansion is limited. However, a push for microgeneration now without consideration of carbon costs would result in increased use of diesel generator sets and other fossil-fuel generation. This growth may occur anyway for peak shaving and to avoid blackout risk. From an environmental viewpoint, this would increase carbon emissions and localised pollution.

IV. 14. Energy efficiency has been described as the cheapest and safest way to meet new energy goals[74]. However, our electricity market is relatively poor at delivering energy efficiency. There is clear evidence of the benefits of targeted interventions. The recent Ecobulbs promotion reduced energy demand at a cost of less than 1.5 c/kWh, as opposed to 6-8 c/kWh for new generation[75]. The current strategy for energy efficiency, the National Energy Efficiency and Conservation Strategy (NEECS), lacks mechanisms and forces for change. In essence it lacks the teeth it needs to be effective. We are not on track to meet the NEECS energy efficiency target for 2012[76].

IV. 15. An effective, liquid and transparent market in energy securities could put a price on the right to be supplied a specific quantity of energy at a specific time. This would allow a better balance between supply and demand investments, helping investors on either side of the meter to make economically efficient decisions.

IV. 16. For the level of energy efficiency to increase, investment must shift across the meter to the demand-side. Effective policies already exist for improving home insulation, and the tightened building standards have been effective[77]. Minimum energy efficiency standards are welcome but should be expanded and tightened. There is a role for market based solutions as well as mandated improvement.

IV. 17. Energy efficiency improvement targets of 2% per year are achievable, but research is needed to understand the effective drivers for energy efficiency decisions and to minimise unintended consequences from efficiency interventions.

IV. 18. Coal is not a sustainable option for the long term, unless breakthroughs are made in capturing, separating and sequestering the carbon dioxide emitted when coal is burnt in a safe and secure way, at an acceptable cost. In principle, it will be very difficult to guarantee that storage of carbon dioxide over hundreds of years will be secure[78].

[73] E.ON UK plc "Performance of Whispergen micro CHP unit in Carbon Trust field trials", May 2006

[74] DTI Energy White Paper, "Our energy future – creating a low carbon economy", 2003 http://www.dti.gov.uk/energy/energy-policy/energy-white-paper/page21223.html

[75] Electricity Commission, "Residential Compact Fluorescent Programmes – Request for proposals", May 2006

[76] IEA, "Energy Policies of IEA Countries – New Zealand", 2006

[77] IEA, "Energy Policies of IEA Countries – New Zealand", 2006

[78] A recent, in-depth summary of carbon dioxide capture and storage (CCS) has been published by the IPCC as a special report. Substantial research investment is being made globally into CCS, hence its costs and viability may change.
http://www.ipcc.ch/activity/srccs/index.htm

IV. 19. There are three main methods of sequestration: (1) scrubbing emissions followed by deep ocean disposal; (2) disposal by pumping the gas into deep oil wells or saline aquifers; (3) capture in solid material as inert carbonates which can be dropped safely in the ocean. Given concerns over acidification and the possible instability of the material deposited, (1) appears to be unacceptable. The level of tectonic activity in New Zealand suggests that both (1) and (2) could have additional risks in the long-term[79]. The safest procedure for New Zealand is (3), but present predictions of costs are higher than for other options.

IV. 20. If carbon capture and sequestration technologies can be developed and deployed at an acceptable cost, then New Zealand's vast reserves of coal can be used in an environmentally acceptable manner. However, the expected cost of capturing carbon dioxide from the exhaust of a coal-fired generator may raise the cost of the generated electricity by 30-90%[80]. Hence other ways to use our domestic coal resources may be more fruitful than simply burning the coal. Collection of coal seam methane or in-situ reformation are potential options.

IV. 21. Cost increases and the technical and geological risks of sequestration mean that New Zealand's energy supply will be dominated by renewables as far as electricity and transport are concerned. Oil/gas/coal generation will definitely be required in the short term as the lead times to develop and install the renewable sources of energy that will make a difference will be long, hence the sense of urgency that needs to be created in terms of energy strategy and focused research.

[79] IPCC, "IPCC Special Report on Carbon dioxide capture and storage", 2005, Chapter 5, p213, "Basins located in tectonically active areas, such as those around the Pacific Ocean …, may be less suitable for $CO_2$ storage and sites in these regions must be selected carefully because of the potential for $CO_2$ leakage" http://www.ipcc.ch/activity/srccs/index.htm

[80] IPCC, "IPCC Special Report on Carbon dioxide capture and storage", 2005, Table TS 10. http://www.ipcc.ch/activity/srccs/index.htm

# BACKGROUND TO A ZERO-CARBON ELECTRICITY SYSTEM

## 1. Renewable Supplies

### Current Renewable Potentials

New Zealand's supply of gas and oil is declining. Our self-sufficiency in oil has dropped from a peak of 65% to the current level of 25%. In the last 10 years and increasingly in the last five years the use of imported fossil fuels has replaced declining domestic oil and gas production. Our imports of coal leapt from nil in 1998 to 800,000 tonnes in 2005[81]. We are increasingly exposed to the fluctuations of international oil prices. Our gas reserves are declining so that within the next 15 years we will no longer be able to meet our gas requirements without either further exploration success or reduced consumption.

Electricity demand rises inexorably by about 2% per annum and we will increasingly have to buy oil and potentially gas in the form of LNG or CNG on the international market. Both our balance of payments and our security of supply will be harshly affected if we are unable to either replace or substitute alternative fuels for these imports.

Whilst we have large reserves of coal, our commitment to the Kyoto Protocol and obligations to meet reductions in $CO_2$ emissions make the recent increase in coal use and any further commitment to coal-fired generation plant unattractive. The abandonment of a carbon tax fails to price into the use of coal the costs of meeting our Kyoto commitments and delays significant investments in alternative fuel sources.

Wind developments are now largely commercially driven but further research into regional and site-specific wind resources and prediction is justified. 935 MW of wind generation is planned. More than 2000 MW may be possible by 2016, making wind energy a substantial fraction of our future power supply[82], if wind energy is strongly supported.

Biomass fuels offer significant potential either as residues or energy crops to provide heat and supply electricity. However, electricity generation will have to compete with transport fuel as an end-use for biomass.

There has been a resurgence of geothermal prospecting and new generation technologies are now available, which are both more efficient and which require lower temperatures to be economic. New areas, previously sub-economic, may now be potentially attractive. Currently, geothermal power provides 450 MW of generation, but has the potential to provide in excess of 1000 MW more[83], possibly as much as 3600 MW[84], more than 40% of our current electricity demand, and to do so sustainably with current technology, known costs, 90% lower carbon emissions than coal-fired generation and higher reliability than any other source. The only major difficulties are those associated with regulatory barriers and with the loss of experience from the industry.

New Zealand should also consider evaluation of ambient-temperature geothermal technologies, such as ground-source heat pumps, as options for domestic heating and cooling.

Whilst large-scale hydro may be close to fully developed, there are ample opportunities for smaller-scale, less intrusive and demanding of water resources, which could be developed. Small-scale irrigation-related generation schemes are also possible.

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[81] MED, "Energy Data File", January 2006, Table C.3

[82] Electricity Commission, "Scenarios for the Wind Generation Investigation Project", December 2005

[83] MED, "Existing and Potential Geothermal Resource for Electricity Generation", December 2004 http://www.med.govt.nz/templates/MultipageDocumentTOC____12518.aspx

[84] NZGA, "Geothermal Energy: New Zealand's most reliable sustainable energy resource", February 2006 http://www.nzgeothermal.org.nz/publications/Submissions/2006Feb_NZGA_PS.pdf

Some of the fuel types and technologies produce intermittent electricity. The effects of this intermittent supply can be offset by research into forecasting and diversity of fuel-type and geographic distribution. Nonetheless, meaningful increases in the use of intermittent renewables will require improved connection standards and protocols as well as a strong and secure transmission grid. Distributed generation should be encouraged as regional energy generation becomes more popular and electricity distribution companies are able to profitably invest in generation assets. Regional solutions and community ownership should be encouraged. New Zealanders should be encouraged to invest in energy – from oil and gas exploration through to community-owned micro-generation.

The Projects to Reduce Emissions was an attractive way to encourage investment in indigenous renewables. If the mechanism is not extended, new incentive schemes, such as feed-in tariffs or guaranteed prices for electricity generation from renewable sources should be considered as part of the revision of the National Energy Efficiency and Conservation Strategy. Government-funded research into energy supply, demand and energy systems needs to be expanded but with a proportionate shift in focus to renewable fuel types and technologies.

**Future Renewable Potentials**

The first megawatt-scale commercial wave energy installation will be operational this year offshore Portugal[85]. The first pre-commercial tidal stream generator will be operational before the end of this year in Strangford Lough, Northern Ireland[86]. Marine generation technologies are at a stage similar to wind generation twenty years ago, with many different prototypes and pre-commercial technologies being trialled on a commercial basis. Given the state of development, marine energy generation is not yet cost-competitive with other technologies. However, with the urgent global push for renewable power, we see rapid action to lower costs through design optimisation and economies of scale such as the UK's investment of NZ$150 million in a Marine Renewables Deployment Fund[87] and the Portuguese and Spanish governments feed-in tariffs to create market pull[88]. These subsidies rapidly drive down the cost of marine generation and are expected to provide a net saving overall[89]. The Electric Power Research Institute has calculated that the long term price of marine-generated electricity may be equivalent to or lower than the cost of wind-generated electricity[90].

Marine generation in Scotland may provide 1300 MW by 2020[91]. New Zealand's potential supply is not well characterised but, given that it has 50% longer coastline and a more widely distributed population, it is likely to be greater than the figure for Scotland. Unlike Scotland, our major best locations for tidal generation are situated close to major users. Both wave and tidal energy generation is intermittent, but tides are very predictable on a daily basis and wave energy is predictable days in advance. Both are likely to provide more energy during winter when seasonal electricity demand is high. Marine energy may also be complementary to other forms of intermittent renewables.

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85 Ocean Power Delivery Ltd, "World's First Wave Farm – Shipping Of First Machine To Portugal" http://www.oceanpd.com/docs/OPD%20ships%20first%20machine%20to%20Portugal.pdf

86 http://www.marineturbines.com/

87 http://www.dti.gov.uk/energy/sources/renewables/business-investment/funding/marine/page19419.html

88 Marine Energy Group, "Harnessing Scotland's Marine Energy Potential", 2004 http://www.scotland.gov.uk/Publications/2004/08/19742/41047

89 The Carbon Trust, "Future Marine Energy: Results of the Marine Energy Challenge: Cost competitiveness and growth of wave and tidal stream energy", 2006 http://www.carbontrust.co.uk/technology/technologyaccelerator/marine_energy.htm

90 Electric Power Research Institute, "Economic Assessment Methodology for Offshore Wave Power Plants", report E21 EPRI WP – US – OO2, November 2004 http://www.epri.com/attachments/297213_002_Rev_4_Econ_Methodology_RB_12-18-04.pdf

91 Marine Energy Group, "Harnessing Scotland's Marine Energy Potential", 2004 http://www.scotland.gov.uk/Publications/2004/08/19742/41047

Wave and tidal stream resources are reportedly 'tremendous'[92] but there are insufficient physical measurements to detail the economic potential. Marine energy technologies are being developed internationally and New Zealand will be able to benefit from these investments but domestic expertise is still required. Research into support activities, such as resource assessment, mooring, bio-fouling and policy analysis are required.

The cost-effective level of renewable supply for New Zealand is constantly increasing. Work by the US National Renewable Energy Laboratory has shown continuing declines in the cost of renewables as technologies mature, shown in Figure 5. For wind power, the price of a kilowatt-hour of wind-produced energy has fallen by 80% over the last twenty years. The economics of wind power depend upon the size of the turbines. These have yet to reach an upper limit and so the cost continues to fall.

Hence a commitment to generation using renewable energy will become ever easier to hold to, whereas long term investments in fossil fuels will not.

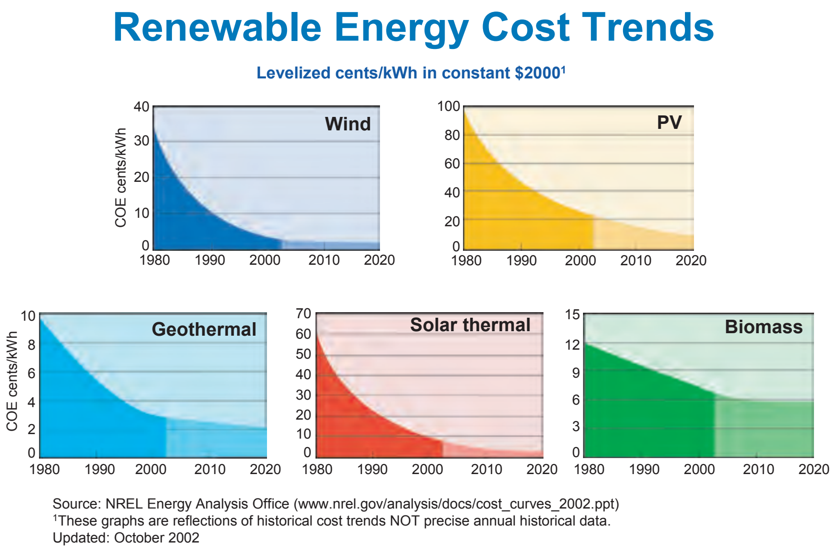


**Figure 5:** Source: NREL Energy Analysis Office[93]
These graphs are reflections of historical cost trends not precise annual historical data. Updated: October 2002. For biofuels, the curve represents expected future costs for gasification, not for cellulosic ethanol, and the curve does not take into account byproducts.

## 2. Nuclear power

Some countries in Europe and the US are looking back to nuclear power as a source of carbon-free electricity. New nuclear power stations are being built in Finland, India, Japan and China[94]. However, nuclear power is ruled out in NZ for several reasons. The expense of nuclear power depends upon government support and exchange rates; one collection of estimates gives a cost of around 10 NZc/kWh[95]. At that price, nuclear power is substantially more expensive than our abundant renewable resources. Other difficulties make nuclear power unattractive. The scale of our electricity system poses problems. Currently available nuclear plants are similar in size to Huntly, leading to difficulties when generating plant needs to be shut down for maintenance. We have no experience with the technology and would have to import both equipment and personnel to run a plant. The uranium ores discovered in New Zealand in the 1950s are very low grade[96]

[92] NIWA, "Ocean bounty: energy from waves and tides", in Water & Atmosphere, 2005, volume 13, number 4, pp16-17.

[93] www.nrel.gov/analysis/docs/cost_curves_2002.ppt

[94] World Nuclear Association, "Plans for new reactors worldwide", 2006 http://www.world-nuclear.org/info/inf17.htm

[95] Thomas, S, "The economics of nuclear power: analysis of recent studies", Public Services International Research Unit, 2005, Table 8 http://www.psiru.org/reports/2005-09-E-Nuclear.pdf

[96] A brief history of the West Coast Uranium Rush can be found at: http://www.teara.govt.nz/EarthSeaAndSky/MineralResources/RadioactiveMinerals/3/en

so nuclear fuel would also have to be imported and world market prices paid. Nuclear power has demonstrated poor reliability; UK plants have only managed lifetime load factors of 60%[97], against an expected load factor of 85%.

Globally, the low social acceptance of nuclear power is due its high end-of-life cost, safety record, waste disposal and inherent connections with nuclear weapons proliferation. These factors also apply in New Zealand.

## 3. Demand side management and efficiency

New Zealand has a history of relatively low energy prices, especially for electricity, and reasonably high supply security which has led to an energy intensive economy. Domestic and international energy pressures are reducing security and raising energy costs and this seems likely to worsen. One promising path is to manage the demand for energy by improving energy efficiency. This demand side path should have lower costs and greater benefits than corresponding energy supply solutions but there are numerous barriers and insufficient incentives to overcome them. Many of the benefits from improved energy efficiency and demand management provide significant public good. Therefore there is a case for intervention on the demand side. If this is done well then unintended consequences will be small[98].

## 4. Our electricity system

Our historical secure energy supply from traditional low cost hydro and Maui gas cannot provide future energy security in the face of further demand growth, resource consent uncertainties for hydro and wind and doubts about continued availability of natural gas. New hydro generation is expected to be priced above current wholesale prices (6-7 c/kWh)[99]. Generation with imported liquefied natural gas as a substitute for gas from Maui, is priced by industry sources at 6.8-7.5 c/kWh assuming a national scale of operation[100]. This is still high compared to historic costs. Large supply extensions are feasible using renewable generation such as wind, or using coal but these will result in higher prices. New Zealand also faces significant additional costs on the international market due to its increased carbon emissions in the first Kyoto commitment period from 2008-2012[101]. The current push to increase renewable energy use will reduce these but at present, it appears that this push is not enough to avoid all our carbon obligations.

Current prices may be insufficient to secure investment in new generating capacity[102]. More than two-thirds of New Zealand's electricity is generated by hydro and geothermal[103]. These systems have high capital costs and inherently low operating costs.

[97] Thomas, S, "The economics of nuclear power: analysis of recent studies", Public Services International Research Unit, 2005, Table 6 http://www.psiru.org/reports/2005-09-E-Nuclear.pdf

[98] Carrington, C. G., Rutherford, J. P., Scharpf, E. W., "The Challenge of Consumer Energy Efficiency". Conference proceedings, "People and energy: how do we use it?" Royal Society of New Zealand, Christchurch, 18 November 2004, Pp. 34–43. Royal Society of New Zealand, Miscellaneous Series 66, 2005

[99] MED, "Availabilities and Costs of Renewable Sources of Energy For Generating Electricity and Heat Report to the Ministry of Economic Development", By East Harbour Management Services Ltd, September 2002

[100] Contact Energy, "Liquefied Natural Gas:. a viable backstop option for New Zealand, Update on Contact Energy and Genesis Energy joint feasibility study" http://www.mycontact.co.nz/pdf/financial/lng_briefing_nov04.pdf

[101] Hodgson, P. "Climate change challenge increases in New Zealand", 16 June 2005 http://www.beehive.govt.nz/ViewDocument.aspx?DocumentID=23376

[102] Marsden, A., Poskitt, R. and Small, J. "Investment in the New Zealand Electricity Industry". UniServices Ltd, Auckland. Ref 10679.00. 2004

[103] MED, "New Zealand Energy Data file", July 2004

The capital is already invested so the marginal cost of generating electricity from these sources is extremely low, providing low wholesale power prices most of the time. The high fraction of generation from hydro with limited storage capacity, combined with low winter inflows and a winter demand peak causes a wide variation in the price of electricity. In a wet year with a large amount of hydro power available, the wholesale price can be extremely low. Any fuel-fired generator with significant costs for fuel will operate at a loss during these periods, if they run at all. Furthermore, if there is an increase in generating capacity from high-capital low-operating cost generation such as wind, extended periods of low wholesale electricity prices will continue.

On average, low prices are very beneficial, but this system does not create a market route to security of supply. Thus arises the expectation of electricity price rises in New Zealand to provide that security. This problem, in combination with two exceptionally 'dry' years that limited hydro-electric generation in 2001 and 2003, raise concerns that the electricity market will not provide adequate supply security in the face of demand growth. These issues echo international concerns about the adequacy of investment in electricity production and networks, in liberalized markets[104].

## 5. Why we are not efficient

New Zealand's energy efficiency is no better than it was in 1977. It has shown a downwards trend for the last eight years[105]. Between 1973 and 2002, total electricity generated increased at an average rate of 2.6% pa. The corresponding rate of population increase was 0.9% pa and the GDP increased at 1.9% p.a.[106].

There is a clear relationship between the average national price for electricity in per kWh and the structural electricity intensity of 24 OECD nations, expressed in kWh per $GDP[107]. The relationship shows that when prices are higher, OECD economies tend to have lower electricity intensity. Currently New Zealand's economy has a relatively high electricity intensity which is the likely result of the relatively low current and historic electricity prices.

## 6. Decoupling our energy use and our economic growth

Security of supply, environmental management and economic efficiency form the basis of modern energy policy. Energy efficiency is complementary to all three yet realised levels of efficiency remain well below the most cost-effective equilibrium. The IEA shows that in order for the level of energy efficiency to increase, investment must shift across the meter to the demand-side[108]. But a variety of behavioural or organisational barriers, often underpinned or exacerbated by information constraints, retard investment in energy efficiency.

The current level of efficiency is below the optimum cost-effective levels derived using engineering and economic models[109]. The reasons for the disparity between realised efficiency and the economic potential for efficiency are complex with many resulting from organisational or behavioural causes.

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[104] Borner, A. and MacKerron, G. "Who secures the security of supply? European perspectives on Security, Competition and Liability", The Electricity Journal, December 2003, 10-19

[105] IEA, "Energy Policies of IEA Countries – New Zealand", 2006

[106] IEA, "Electricity Information (2003 Edition) Part II", 2003

[107] Verbuggen, A. "Stalemate in energy markets: supply extension versus demand reduction", Energy Policy, 200331, 1431-1440

[108] IEA, "World Energy Outlook 2005", 2005

[109] Sanstad, A. and Howarth, R. "'Normal' markets, markets imperfections and energy efficiency", Energy Policy, 22, 811-818
Jaffe, A. and Stavins, R. "The Energy efficiency gap – What Does it mean, Energy Policy", 22 (10), 804-810
Weber, L., "Some reflections on barriers to the efficient use of energy". Energy Policy 25 (10), 833-835

## 7. Organisational Causes

When power generation companies make long term investment decisions, they decide based on their own interests. They do not necessarily consider external issues like system security[110]. There is no direct market for security of supply nor are there adequate long term instruments to act as a proxy for this market. Reserve generation is essential for supply security but the current market incentives for investing in reserve generation are limited to either high spot prices in rare periods of shortage or premiums paid for long term contracts. These are rare since liquid electricity futures markets do not exist in New Zealand for the decadal timeframes required to hedge the price risk for generation projects.

Further, there is little incentive for individual consumers to develop grid-connected reserve generation. The cost would be carried by those consumers alone while the additional reserve and security benefits the entire grid.

## 8. Bounded Rationality

Bounded rationality resulting from the organisational structure of firms is a common theme in explaining this deviation from optimally efficient behaviour[111]. Reasons include 1) the dislocation of individual and collective interests, 2) the satisficing rather than maximizing nature of investment decisions, 3) asymmetric information, and 4) moral hazard where one or more parties involved in an agreement have incentives to act contrary to the principles of that agreement. A tendency to focus on short term cost decisions can also contribute to actions which are less than optimal over the long term.

Other research, focusing on consumers rather than companies, suggests levels of energy use are affected by differing social status, feelings of competence, interest in technologies and general culture[112]. Cultural and political differences between Swedes and Americans are important variables in explaining the differences in their energy use[113]. Economic analysis views the energy users as investors but viewing energy users as members of a social group and energy consumption as an expression of personal values helps to better explain the actions of individuals[114]. Other organisational and behavioural barriers to energy efficiency include: perceived risk, dislocation of costs and benefits, lack of access to capital, imposed-choice, newness of technology, additional expertise and attention required to maintain efficiency investments, split incentives and culture.

## 9. Information Barriers

Many barriers are associated with energy efficiency information. The market may fail to provide the levels of consumer efficiency indicated by the cost-effective potential primarily because of informational problems[115]. Consumers are relatively unfamiliar with many energy efficiency measures and the benefits of energy efficiency are often difficult to quantify before they are purchased. The public good nature of information, and therefore the tendency of the market to undersupply it, is a well documented barrier to energy efficiency[116].

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[110] Borner, A. and MacKerron, G. "Who secures the security of supply? European perspectives on Security, Competition and Liability", The Electricity Journal, December 2003, 10-19

[111] DeCanio, S. "Barriers within firms to energy-efficient investments", Energy Policy September, 21(9), 906 - 914

[112] Robinson, J. "The proof of the pudding: Making energy efficiency work", Energy Policy, 19 (7), 631-645

[113] Erickson, R. " Household energy use in Sweden and Minnesota: individual behavior in cultural context", in W. Kempton and M. Nieman, eds, Energy Efficiency: Perspectives on Individual Behavior, American Council for an Energy-Efficient Economy, Washington, DC, 1987, 213-228

[114] Stern, P. and Aronson, E., eds, "Energy Use: The Human Dimension", Freeman, New York, NY

[115] Huntington, H., Schipper, L. and Sanstad, A. "Editors' introduction", Energy Policy 22 (10) 795-797

[116] Sanstad, A. and Howarth, R. "'Normal' markets, markets imperfections and energy efficiency", Energy Policy, 22, 811-818
Jaffe, A. and Stavins, R. "The Energy efficiency gap – What Does it mean, Energy Policy", 22 (10), 804-810

This is an example of Akerlof's 'market for lemons', which showed that this information asymmetry can lead to the removal of the higher priced, higher quality products, causing a downward spiral in the both the price and quality of products in the market[117]. The problem worsens in the second-hand markets where the sellers have very good knowledge of the product, but the buyers have very little, and there are few institutional guarantees.

Thus there are many public-good reasons for addressing these impediments, since improved energy consumer efficiency has significant benefits to both the environment and to supply security, which are currently not allocated to the actor that achieves the efficiency.

## 10. Why we are not secure

We use the term energy security to refer to a generally low business risk related to energy with ready access to a stable supply of electricity/energy at a predicable price without threat of disruption from major price spikes, brown outs or externally imposed mandatory limits.

A secure electricity supply is not a pure public good in the economic sense because is it rival - one party's use limits another - and exclusive – users can be excluded by having their supply turned off. However, all users benefit from the supply security that comes from the relatively stable behaviour of other users.

The cost of this supply insecurity to the New Zealand economy is difficult to estimate. The economic costs of the dry-year shortages in 1992, 2001 and 2003 have been estimated at 1.5% of GDP in 1992 (approx US$800M), several hundred million dollars for the 2001 drought and a similar amount for 2003[118]. The cost of supply insecurity is far above the price of the electricity not purchased, by a factor of perhaps one hundred times.

## 11. Benefit of Energy Efficiency and Security

There will always be some level of trade-off between the price of energy and energy security. However, it should be possible to improve both the security of supply and keep prices more stable because demand growth management has a much shorter response time than installing new generation capacity.

The investment balance between demand side management and supply side generation is not a level playing field, the generation side is favoured. Therefore increasing net service capacity can be done more cheaply with efficiency improvements rather than with new generating capacity, making lower overall prices possible. Hence consumer efficiency offers a positive opportunity for smoothing New Zealand's transition away from heritage-hydro and low-cost Maui gas to more expensive, but available and acceptable, sources[119].

## 12. Policies and Actions

In 1996, the New Zealand Ministry of Energy[120] noted that "… the reserves of conserved energy which we have identified could supply 55% of the electricity, 34% of the wood and coal and 42% of the gas required in the nation's houses in the year 2000". Almost two

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[117] Akerlof, G. "The market for "lemons": quality uncertainty and the market mechanism", The Quarterly Journal of Economics, 84, (3) 488-500

[118] McKerchar, A. and Woods, R."The drought of summer-autumn 2003", Water Resources Update NIWA No. 3 2003

[119] Carrington, C. G., Rutherford, J. P., Scharpf, E. W., "The Challenge of Consumer Energy Efficiency". Conference proceedings, "People and energy: how do we use it?" Royal Society of New Zealand, Christchurch, 18 November 2004, Pp. 34–43. Royal Society of New Zealand, Miscellaneous Series 66, 2005

[120] MOE "Supply Curves of Conserved Energy: The Potential for Conservation in New Zealand's Houses", Prepared for the former Ministry of Energy, New Zealand

decades later EECA suggested that "…within individual business or institutions energy efficiency improvements of 15-25% are typically achievable over three to five years"[121].

While some industries claim that they use best practise, the clear increase in energy efficiency in OECD countries over the last twenty-five years shows that 'best practise' is continually improving[122]. The link between energy prices and energy efficiency[123] shows that industries are not governed by best practise but by which technologies are cost effective for particular business environments.

For eleven OECD countries, their energy intensity improved from 1973 to 1998 by an average of 1.8% per year. The majority of this improvement came from energy efficiency, structural changes from energy intensive industries being driven offshore accounted for no more than 0.3% of that improvement[124].

*There is no reason why New Zealand could not achieve similar grow rates in energy efficiency. Indeed, as our energy efficiency improvements over the last eight years have shown, it should be easier for us to catch up with the other rich nations.*

Presently the existence of public-good attributes of energy efficiency and their unrealised cost-effectiveness has motivated some governments to intervene with regulations or incentives to overcome these barriers. For maximum impact, these policies should focus around creating obviously visible benefits. This may be more effective than price subsidies or greater knowledge of energy efficiency[125].

In theory it is desirable for these measures to be supported by market-based mechanisms because they would minimise distortions in the market and would more accurately reflect consumer preferences. Market oriented measures like energy performance contracting and industry initiated environmental labelling have the potential to create a robust demand for consumer efficiency. Although these measures may require initial activation, they offer the potential for spontaneous, embedded, long term market-driven increases in energy efficiency, without the need for ongoing political endorsement.

Selective demand reduction will reduce the need for investment in both generation and transmission with minimal negative impacts on the users who reduce their inefficient demand. Using demand side management can allow delaying supply side investment, having a beneficial impact on prices without reducing the profits on the supply side. This would both delay and moderate the impact on electrically intensive industries, as the present cost of future supply extensions tends to decrease with time as newer supply technologies emerge. From a system security perspective, reducing inefficient demand is an acceptable substitute for increasing supply since both methods increase reserve capacity. From an environmental perspective, reducing inefficient demand is an even more promising alternative as demand reductions usually do not incur the negative environmental consequences typically associated with supply extensions, such as RMA difficulties and the NIMBY problem.

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[121] EECA "National Energy Efficiency and Conservation Strategy: Towards a sustainable energy future", September 2001, EECA and MFE 01

[122] IEA "The experience with energy efficiency policies and programmes in IEA countries – learning from the critics", 2005.
http://www.iea.org/Textbase/publications/free_new_Desc.asp?PUBS_ID=1567

[123] Verbuggen, A. "Stalemate in energy markets: supply extension versus demand reduction", Energy Policy, 200331, 1431-1440

[124] IEA "The experience with energy efficiency policies and programmes in IEA countries – learning from the critics", 2005
http://www.iea.org/Textbase/publications/free_new_Desc.asp?PUBS_ID=1567

[125] Ball, R., Cullen, R., Gan, C., "The diffusion of energy efficiency innovations among residential energy consumers", New Zealand Economic Papers, volume 33, number 1, 1999, pp115-135

An obvious example of an intervention that is proving successful is the Energywise home insulation retrofits. However, this scheme is small; by 2016 only one-third of inadequately insulated homes will have been improved[126]. Expanding this scheme seems an obvious step. Tightening building regulations is another required action. A building's energy requirements are hard to change after construction, yet developers have little incentive to improve building energy performance. Hence minimum energy standards are useful in this case.

## 13. Market solutions

The majority of the policies cited in the World Energy Outlook alternative policy scenario[127] are either regulation or incentive schemes such as minimum energy performance standards, subsidies and research support. Such measures are commonly used to fill the gap when existing market mechanisms stop short of achieving economically optimal energy efficiency. In many cases, intervention has proved to be highly effective. One example is the intervention into the UK home refrigerator market, which had been the target of market transformation policies[128]. The implementation of performance labels and required minimum energy performance standards led to the average efficiency of refrigerators improving 40% between 1990 and 2004.

Regulation or incentive schemes can be very effective but they can also be fragile in the long term because they require sustained political endorsement. The UK's minimum energy standards for refrigerators were highly successful but its planned second stage was not implemented because of the lack of political support. Market-based solutions, which improve the alignment between investment and reward, have the potential to produce increases in energy efficiency more naturally and equitably, but have often been overlooked.

A solution to the informational problem expressed by Akerlof's 'market for lemons' is institutional guarantees backed by the government or by another organisation with high credibility. Government intervention is also used to some extent to inform consumers, so as to reduce some of the information asymmetries in the market. In New Zealand newsletters like EECA's EnergyWise News and schemes such as mandatory energy performance labelling are currently used. Performance labelling schemes provide consumers with better information so that they can make a more informed decision. Similarly eco-labelling schemes allow consumers to exhibit their preferences towards products with a lower environmental impact[129].

In the electricity sector, decreased electricity demand, similar to increased electricity supply, improves system security as both create greater net reserves and therefore greater reliability. All electricity consumers benefit from the greater security while suppliers can also benefit since investment in both network and generation capacity can be delayed. This in turn delays the negative environmental effects associated with these supply side investments.

Energy efficiency improvements provide further quasi-public good benefits in the context of the Kyoto agreement. Here the benefit takes the form of deferred installation of new generating capacity which has a net carbon output.

[126] EECA, "Annual report", 2005

[127] IEA, "World Energy Outlook", 2004
http://www.iea.org/Textbase/publications/free_new_Desc.asp?PUBS_ID=1266

[128] Boardman, B. "Energy efficiency through product policy: the UK experience", Environmental Science & Policy ,7, 165-16

[129] Hume, J. "Do our customers care about the sustainability of New Zealand's key exports?" Winston Churchill Fellowship Report. Co-sponsored by the New Zealand Business Council for Sustainable Development.

## 14. Unintended consequences and rebound effects

Efficiency makes energy services such as light and heating more affordable. In response, do consumers increase their consumption of services and negate these savings? An in-depth review of the empirical evidence in Europe and the US for residential, industrial and transport users suggests that this effect is small, of the order of 20-30%[130]. EECA themselves use a conservative 30% figure[131]. The rebound effect exists but is not a reason to avoid energy efficiency interventions. Even when people chose to take their savings as expanded services, e.g. as a warmer house, then general welfare is increased by energy efficiency.

Similarly, some argue that improved energy efficiency can lead to improved economic growth, raising energy use and cancelling out the gains. Empirical studies have shown that this effect is tiny, less than 2% of direct energy savings. Instead, there is some evidence to suggest that when households and businesses save money on energy, they respend in more labour intensive and productive areas of the economy, increasing employment and overall production[132].

Do higher energy prices and more stringent efficiency regulations drive energy intensive industries offshore? Again, the empirical evidence suggests that this effect is small. In eleven countries studied by the IEA, the effect on energy use of structural changes was far smaller than changes in efficiency, by a factor of at least four[133].

## 15. An Energy Security Market

Providing an explicit security market could assist in setting the optimal quantity of reserves while automatically achieving an efficient balance between supply and demand side initiatives. It would also have the advantage of removing the need for ongoing political support and intervention. If such a market were successful at providing a longer term signal for investment, it could smooth overall investment throughout the energy system.

In this proposed Electricity Security Market, the right to draw a specific quantity of energy from the network under certain pre-determined conditions would be purchased by new electricity consumers and sold by suppliers who are able to guarantee, subject to clear requirements, that the additional electricity will be provided according to an agreed schedule. One form this could take would be through a series of security levels where suppliers of capacity (through either increased generation or reduced consumption of its other customers relative to established base loads) would have to release or provide that additional capacity to the grid. Shown as a simple schematic in Figure 6, the market would be constructed to create greater symmetry in investment between supply and demand-side options for increasing security.

As shown in Figure 6, the market would be constructed to create greater symmetry in investment between supply and demand-side options for increasing security. Furthermore it would encourage incremental approaches to investment in the energy system, supporting distributed generation and demand-side alternatives where they provide best value. It would reward essentially all actions that increase the security of the system paid for by those who would most benefit from the security. This would link the impact of actions affecting system security to greater financial motivations, encouraging activities like diversifying the fuel mix of generators or demand reductions through to increased energy efficiency by consumers. Such a market could also stimulate investment in efficiency by large industrial consumer companies, which have costs of capital similar to that of energy suppliers as opposed to the higher cost of capital of household consumers.

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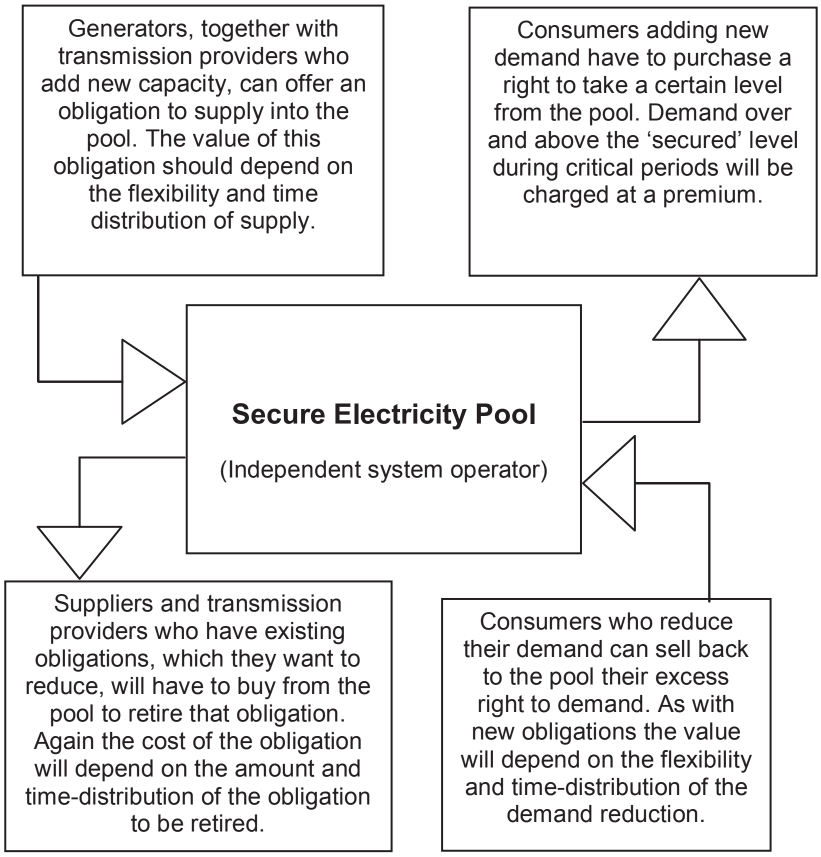
[130] IEA "The experience with energy efficiency policies and programmes in IEA countries – learning from the critics", 2005

[131] IEA, "Energy Policies of IEA Countries – New Zealand", 2006

[132] IEA "The experience with energy efficiency policies and programmes in IEA countries – learning from the critics", 2005

[133] IEA "The experience with energy efficiency policies and programmes in IEA countries – learning from the critics", 2005

**Figure 6:** Schematic of an energy security market




There is a need to identify additional ways to improve the security of New Zealand's electricity supply for those who need that security the most. If it is possible to mobilise the demand side of the energy market to provide some of this security through increased incentives to improve efficiency, there are a number of benefits to be shared by all consumers. Since many of these benefits do not currently carry a price and since their value varies from user to user, it makes sense to consider market mechanisms to harness this value as effectively as possible.

## 16. Carbon capture and storage and the continued use of coal

New Zealand has begun to import coal, but $CO_2$ emissions may limit or prevent the future use of coal to generate electricity. Since the 1970's, the emissions of other pollutants from both vehicles and power plants have been regulated and have improved dramatically with the increased cost born by the market. Can the same type of engineering development can take place at an affordable cost for cleaning up and disposing of $CO_2$ from the world's giant coal-fired power plants?

$CO_2$ capture and sequestration (CCS) should allow the continued use of coal and other fossil fuels if it can be developed and used in an affordable and reliable manner. However, this presents scientists and engineers with physical hurdles at every step of the development path. The issues are different than for previous pollutants[134], which were only trace components in exhaust flows. The scale of the equipment needed to handle the thousands of tonnes per day of a gas and the energy inputs required are closer to production

[134] Such as lead, mercury, nitrous oxides , volatile organic compounds, particulates and sulphur oxide.

operations than emissions control. Estimates of the increase in cost for $CO_2$ capture and sequestration for new natural gas and coal power plants range from 20% to 90%[135]. The methods or possibilities for retrofitting standard coal power plant designs with separation and compression equipment are not yet determined. The methods and capabilities for permanently placing millions of cubic meters of $CO_2$ in the ground are speculative and have not been demonstrated. Indeed a 10,000 year storage life cannot be trialled.

Carbon sequestration will be useful if it is certain to work and available at an affordable price. This is yet to be demonstrated.

**Storage Sites**

In all of the geologic time that biological matter has been accumulated and thermo-processed in the sedimentary layers of the Earth's crust, only a tiny number of geologic structures have trapped the gasses evolved from the process. Considering all of the land area of the Earth, only a fraction has gas trapped under it. Otherwise, oil exploration would not be the hit-and-miss activity that it is. This fact alone gives an idea of probability of finding suitable locations[136].

Geologists estimate that there are orders of magnitude more $CO_2$ and $CH_4$ that has been formed and escaped to the surface than has been trapped in a reservoir[137]. We have drilled holes through and "cracked" most of those rare structures, so storage in old gas and oil fields or even coal seams will now have a reduced probability of success.

Geologists have been enlisted to search for places underground which may be used as disposal sites for $CO_2$ waste. Three trapping mechanisms have been identified: (1) trapping $CO_2$ gas under low permeability capping structures, (2) reaction between $CO_2$ and water or brine in an aquifer, and (3) reaction with minerals in rocks in the aquifer[138]. These structures exist, but we do not know what impact pumping large amounts of $CO_2$ gas into them will have. The liquid reservoirs are not located near existing power plants or coal seams, so additional input of transportation energy would be required.

Permanent storage of $CO_2$ under the sea or bodies of water is seen as a potentially dangerous and environmentally damaging. Capturing $CO_2$ as solid inert carbonates that could be safely disposed of or used as building materials but a great deal of research is required before this is an affordable option.

Permanent storage in the Earth depends on suitable geology, not on human engineering, and thus is a barrier to development. The technology to pressurize $CO_2$ and inject it at great depths has been developed for oil extraction. The one site where $CO_2$ has been injected into saline aquifer, Sleipner, has shown that in just a few years, the gas has travelled through several layers that were thought to be impermeable. The gas can be injected into the ground, but there is a distinct probability that it will migrate. Carbon dioxide must be stored for hundreds of years if sequestration is to reduce climate change. Guaranteeing this storage is, in principle, extremely difficult, hence relying on sequestration as a solution is risky.

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[135] IPCC, "Carbon dioxide capture and storage", Table TS 10. Figures for pulverised coal power plant range from 40-90% increase in the cost of generated electricity. For natural gas combined cycle plants, 35-85%; for integrated coal gasification power plants, 20-80%.. The report also notes that "there is still relatively little experience with … integrated CCS systems" and that "uncertainty still remains about the performance and cost of current and future CCS technology".

[136] Kenneth S. Deffeys, "Hubbert's Peak: the impending world oil shortage", Princeton University Press, Princeton, New Jersey, 2001

[137] R. Allis, S. White, T. Chidsey, W. Gwynn, C. Morgan, M. Adams, "Natural $CO_2$ reservoirs on the Colorado plateau and Southern Rocky Mountains: candidates for CO2 sequestration", Proceedings of the First National Conference on Carbon Sequestration, Washington, DC, May 2001

[138] S. Bachu, W.D. Gunter, E.H. Perkins, "Aquifer disposal of $CO_2$ – Hydrodynamic and mineral trapping". Energy Conversion Management 35 (4) (1994) 269-279.

Because candidate structures are not located at the power plant, the investment in pumping and piping would be required. The technology for pipeline transmission of natural gas over long distances is mature. The cost of methane transport (about 4% of energy value) is recouped from the sale of the product. Gas pump stations are fuelled by the gas, so an alternative system would need to be developed.

**Separation**

Separation is the show-stopper. Separation technology may be well understood but is far from economically feasible. Without separation, the only possibility is to inject the entire emission stream into the ground[139] . However, this would include the overfire air and the atmospheric nitrogen and would make the cost unacceptable. The Chief Scientist of Australia in 2005 stated that "breakthrough technologies" were needed to enable $CO_2$ separation for coal power plants[140] .

Proponents of $CO_2$ sequestration often cite the Slieper Natural Gas $CO_2$ separation and sea-bed injection as a demonstration project. The natural gas being extracted from the North Sea well contains $CO_2$ which must be removed prior to liquefaction. However, the amine scrubbing process used for extracting $CO_2$ from natural gas is problematic when used for extracting $CO_2$ from flue gases containing oxygen, as do flue gases from coal-fired plant. Further problems occur with low quality coal due to sulphur oxides that degrade the amine solvent[141]. Hence experience overseas of separation in natural gas plants may be misleading. Separation of carbon from the exhausts of low-quality coal plants found in New Zealand may be substantially harder.

Amine scrubbing is still under investigation for Integrated Gasification Combined Cycle (IGCC) coal power plants. The IGCC can be run with less excess oxygen. IGCC is discussed with the aim of reducing the $CO_2$ emissions per kWh electricity but separation of $CO_2$ from the more dilute exhaust gases is even more difficult making scrubbing less effective.

Amine scrubbing is currently the lead candidate for separation. Its high costs are leading to many other avenues being explored. However, all dramatically increase costs and lower efficiencies[142].

**Ecological Sequestration**

It has been suggested that the $CO_2$ released from fossil deposits could be sequestered by the terrestrial ecosystem. The nature of the carbon cycle is a continuous up-take and emission of carbon by the ecosystem. The ecosystem millions of years ago contained the now-fossilized carbon so the atmosphere contained much higher $CO_2$ levels. Between 45-34 million years ago the atmospheric carbon dioxide level was up to five times greater than today and the climate was much warmer[143].

[139] Michael McCartney, Director, Research & Technology - ALSTOM Power, Inc., (2001)

[140] International Conference on Sustainable Engineering and Science, Auckland, New Zealand (2005)

[141] IPCC, "IPCC Special Report on Carbon dioxide Capture and Storage" Chapter 3 - Capture of $CO_2$, http://arch.rivm.nl/env/int/ipcc/pages_media/SRCCS-final/IPCCSpecialReportonCarbondioxideCaptureandStorage.htm

[142] Melanie D. Jensen, M.D., Musich, M.A., Ruby, J.D., Steadman, E.N., Harju, J.A. "Carbon Separation And Capture", Plains $CO_2$ Reduction Partnership, June 2005 http://www.netl.doe.gov/technologies/carbon_seq/partnerships/phase1/pdfs/CarbonSeparationCapture.pdf

[143] Mark Pagani, Yale University, "Deep Sea Algae Connect Ancient Climate, Carbon Dioxide and Vegetation", Science Daily, http://www.sciencedaily.com/releases/2005/06/050622134142.htm

If all of the land areas that have been denuded and become deserts could be reclaimed to their original biological loading, then it would be possible to reduce the atmospheric $CO_2$ level by some amount, if no new fossil $CO_2$ were added to the system. Such massive land use changes, in the face of ecosystem collapse and competing pressures for land for food and fuel, seem extremely unlikely. However, mass production of biofuels may make this approach more economically viable and combining biomass production with carbon sequestration offers the possibility of a negative emissions energy system. This possibility should be investigated further[144].

**The Future of Coal – Fired Power Plants**

In the US, the push for lowered emissions of sulphur and nitrogen oxides, carbon monoxide, ozone, lead, mercury and particulate matter raised generating costs and favoured natural gas-fired generation over new coal plants. Sequestration of $CO_2$ is far harder than removing these trace pollutants from flue gases and will have a greater impact on the economics of fossil fuels. No coal plant designs exist with integrated $CO_2$ capture and storage[145]. Optimistic estimates for this technology put the availability at 15-20 years in the future, hence the use of coal may have to be limited until the technology becomes available.

[144] Read, P., Parshotam, A., "Holistic greenhouse gas management: mitigating the threat of abrupt climate change in the next few decades", Massey University, Department of Applied and International Economics

[145] ASME (American Society of Mechanical Engineers), "The Need for Additional U.S. Coal-Fired Power Plants", Position Paper: 05-16 Energy (2005) http://www.asme.org/NewsPublicPolicy/GovRelations/PositionStatements/Need_Additional_US_CoalFired.cfm

# RECOMMENDATION V
# INTERNATIONAL AGREEMENTS AND A PRICE ON CARBON

That New Zealand continue to adhere to carbon emission agreements involving the wider international community. A shift to lower carbon emission systems will enable New Zealand to become an exporter of carbon emission reduction credits.

V. 1. Investment attention is focused on the expectation that a price will be put on carbon emissions to internalize carbon costs. New Zealand should accept that a price should be put upon carbon emissions.

V. 2. The Kyoto agreement already includes mechanisms for trading emission rights and mitigation technologies through the Clean Development Mechanism and the Joint Implementation agreements. We should not ignore these.

V. 3. There will be no silver bullet to solve the problem of climate change. Indeed, one study suggested that no fewer than fifteen technological bullets will be necessary, of which at least seven would be needed in the next fifty years. However, these technologies are already available to us [146].

V. 4. The follow-on International agreement to the Kyoto protocol must include all nations. Kyoto has the potential to work because it set clear goals and costs for not meeting them. The next agreement must do the same. This is a worrying prospect for New Zealand, when we are failing to meet our Kyoto obligations by an expected 64 million tons $CO_2$ equivalent[147] per annum, a factor of 21% above our targets[148]. We can hardly influence these negotiations if we are not seen to be pulling our weight, let alone lead them[149]. At present, we are not pulling our weight and this leaves us at risk when our export markets demand stronger action to address climate change. For example, the growing popular awareness in Europe of ideas such as 'food-miles' puts our food exports at substantial risk. The response to this risk should be for New Zealand to put some substance behind its clean, green image.

V. 5. Twenty years ago, the idea of putting a price on carbon emissions seemed a purely academic idea. Now, trading systems have begun that many countries and regions use to set that price. New Zealand has chosen to avoid a direct tax but we are obliged to pay a high price for our emissions in the present Kyoto commitment period. Within ten years time, we expect that no nation will be able to avoid paying a price for carbon. New Zealand will have to pay the price of the carbon we emit and we will be financially rewarded if our emissions fall.

V. 6. Current carbon markets are not a clear guide to future carbon prices. The price of carbon is limited by the uncertainty of the future costs of climate change. This uncertainty will decrease as the climate change costs rise.

V. 7. It is not yet clear what will set a limit on the price rise hence we may be facing extreme price increases.

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[146] Pacala, S., and Socolow, R. "Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies", Science, 13th August 2004, Vol. 305. no. 5686, pp. 968 - 972 http://fire.pppl.gov/energy_socolow_081304.pdf.

[147] IEA" Energy Policies of IEA Countries – New Zealand", 2006

[148] IEA" Energy Policies of IEA Countries – New Zealand", 2006

[149] Chapman, R., "A way forward on climate policy for New Zealand", Victoria University of Wellington, 2006

V. 8. There is starting to be some evidence that in the very long term, there may be no safe level of carbon emissions, i.e. that our net global emissions must drop to zero[150]. A price mechanism without an emissions cap may be an insufficient tool for this, making regulatory measures necessary.

V. 9. Assuming that an established level of greenhouse gas emissions is enough to stabilise the climate, the future will hold ever-harsher constraints on the emission of green house gases. The price of carbon (and other greenhouse gas emissions) will increase - thus reducing carbon emissions will benefit us domestically, by diminishing the risks to our domestic economy, and internationally, by creating competitive advantage over other nations in the global export market.

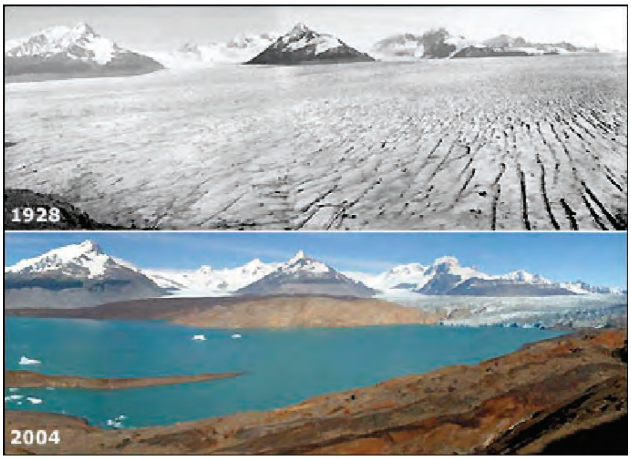
[150] Allen, M, "Climate change modeling and projections", at "Climate change and governance" conference, Victoria University of Wellington, 28-29 March 2006

# INTRODUCTION TO CLIMATE CHANGE

## 1. Certainty

It is clear that humans are influencing the climate and a vast amount of scientific work has only increased the weight of evidence confirming this[151]. A UK recent government report called the evidence linking climate change to carbon dioxide "overwhelming"[152].

**Figure 7:** Retreat of the Uppsala glacier in Argentina from 1928 to 2004.
More than 90% of the world's glaciers are retreating in this manner. The remainder, which are characterised by steep gradients and enhanced snowfall at the top, include several glaciers in New Zealand.



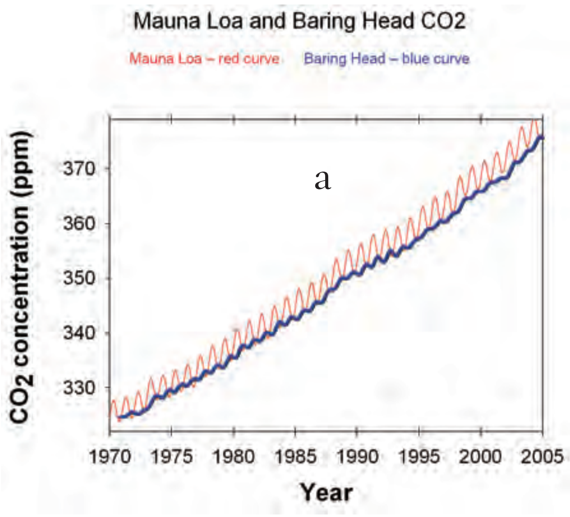

At present, the $CO_2$ concentration in the atmosphere is 379 ppm. There is a 'background level' (pre-industrial revolution) of about 280 ppm at which the average global temperature anomaly may be taken to be zero as a reference. An additional 100 ppm of $CO_2$ has been injected, mostly from Europe and North America during the past century. (At the current net rate of emission, allowing for natural uptake, this amount could have been supplied in less than 40 years.) We may safely assume that the rapidly growing economies of China and India will cause the rate to increase in the short term so that a level of 450 pm could easily be reached within 20-30 years[153]. The atmospheric levels of $CO_2$ have probably not exceeded 380 ppm for at least twenty million years[154].

[151] Recent work includes:
US Climate Change Science Program, "Temperature Trends in the Lower Atmosphere: Steps for Understanding and Reconciling Differences", Synthesis Product 1.1, April 2006, which refuted concerns over satellite temperature record anomalies.
www.climatescience.gov/Library/ sap/sap1-1/finalreport/default.htm
Steffen, Will, "Stronger Evidence but New Challenges: Climate Change Science 2001-2005", Australian Greenhouse Office, Department of the Environment and Heritage
http://www.greenhouse.gov.au/science/publications/science2001-05.html
National Academy of Sciences, "A Closer Look at Global Warming", 2005,
http://www4.nationalacademies.org/onpi/webextra.nsf/web/climate?OpenDocument
National Research Council, "Surface temperature reconstructions for the last 2,000 years", 2006

[152] "Avoiding Dangerous Climate Change - International Symposium on the Stabilisation of greenhouse gas concentrations", Hadley Centre, Met Office, Exeter, UK, 1-3 February 2005
http://www.defra.gov.uk/environment/climatechange/internat/dangerous-cc.htm

[153] The current annual rate of increase for the last ten years has been 1.9 ppm. At that rate, 450 ppm will be reached by 2043.
NOAA Global Monitoring Division, "Trends in Atmospheric Carbon Dioxide", http://www.cmdl.noaa.gov/ccgg/trends/
However, the rate of increase is itself increasing and by 2030, fossil fuel emissions may be 60% higher than at present, if nothing is done to constrain them. At that rate, 450 ppm will be reached by 2033.
Emissions path from IEA, "World Energy Outlook", 2004

[154] Pearson, P.N., Palmer, M.R., "Atmospheric carbon dioxide concentrations over the past 60 million years", Nature, 2000, Vol 406, pp. 695-699



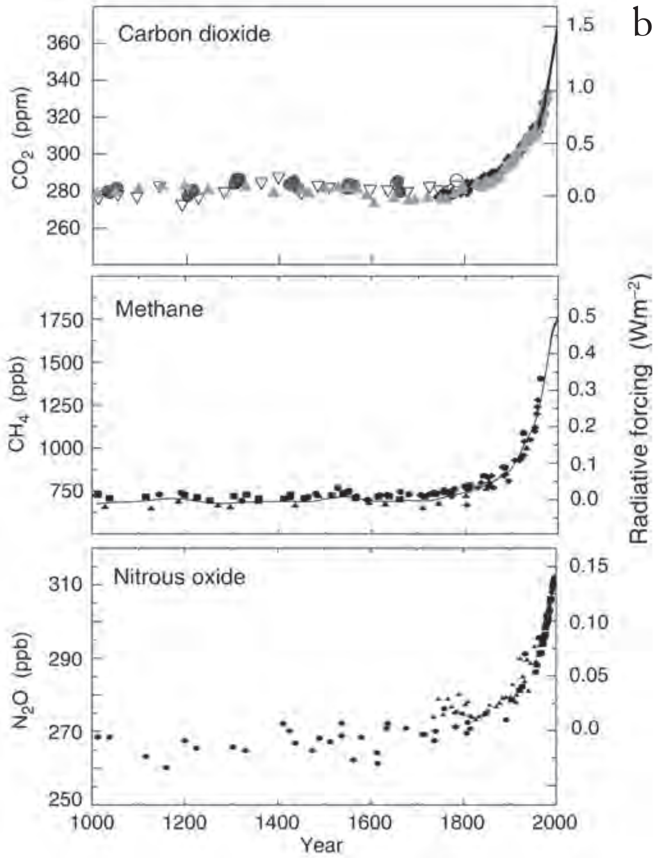
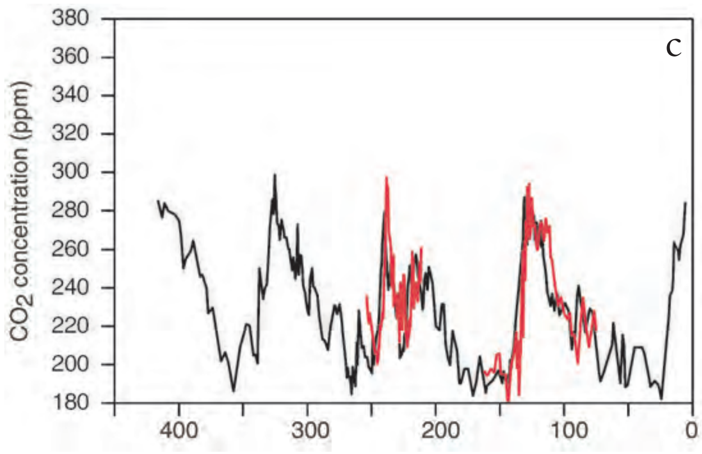




**Figure 8:** Green house gas atmospheric concentrations
a) Atmospheric $CO_2$ concentration in the last thirty years as measured at Mauna Loa in Hawaii and Baring Head near Wellington, NZ[155]. The annual variation is most pronounced in the Northern Hemisphere where most $CO_2$ emissions occur. The variation is the combined result of absorption in the ocean and photosynthesis as well as transport to the Southern hemisphere. The rate of increase currently is 2.6 ppm per year.
b) The atmospheric concentration of the three main greenhouse gases during the past 1000 years.[156] The steep rise beginning after 1800, representing the anthropogenic component, is a consequence of fossil fuel use since the Industrial Revolution.
c) The atmospheric $CO_2$ concentration from the last 400,000 years[157]. Levels have varied between 275-300ppm during the last interglacial warm era, 200 ppm during the last ice age, reaching 280 ppm prior to 1800. The level is now 379 ppm.




[155] Kindly provided by Dr David Lowe, NIWA

[156] IPCC "Third Assessment Report – Technical Summary of the Working Group I Report", Figure 8, 2001 http://www.grida.no/climate/ipcc_tar/wg1/index.htm

[157] IPCC "Third Assessment Report – Technical Summary of the Working Group I Report", Figure 10, 2001 http://www.grida.no/climate/ipcc_tar/wg1/index.htm

**Figure 9:** Known climate drivers – the global annual mean radiative forcing of the climate system for the year 2000, relative to 1750[158].
It is important to recognise that the main greenhouse gas drivers for anthropogenic warming are $CO_2$ (ca.60%), $CH_4$ (ca.20%), $N_20$ (ca.5%) and the halocarbons (ca.15%). Water vapour also provides an important feedback: it is variable and partly produced by the warming due to the other gases, hence it amplifies anthropogenic effects. Although aerosols produced by volcanic activity can have a noticeable effect for a short time after major eruptions. Solar driving has a small but detectable effect with a period of 11 years and occasionally over longer periods (the 'Little Ice Age' around 1700).

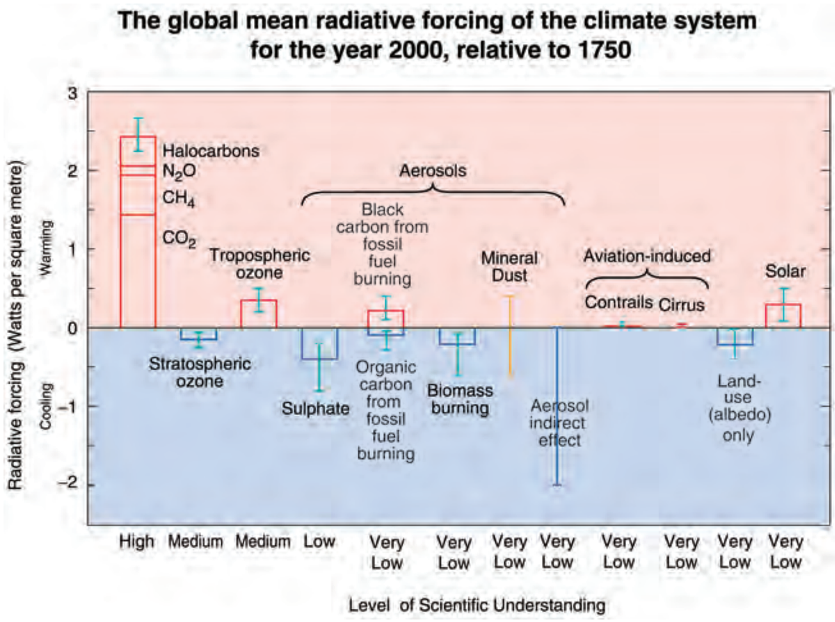
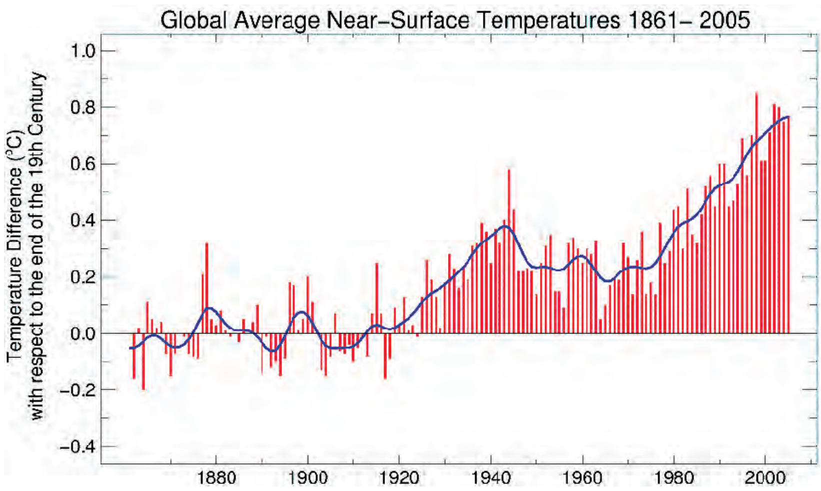



Figure 9 shows the warming impact of sources in addition to carbon dioxide. The warming effect of greenhouse gases far outweighs other effects.

**Figure 10:** The global mean near-surface temperature change measured by thermometers.[159]
The increase since 1860-1900 is about 0.8°C and with respect to the period 1961-1990, about 0.4°C. At the present time millions of measurements are made each year with the result that the accuracy of the annual mean is better than ±0.07°C[160].




[158] IPCC "Third Assessment Report –Summary for Policymakers", Figure 3, 2001 http://www.grida.no/climate/ipcc_tar/wg1/index.htm

[159] HM Treasury, "Stern Review On the Economics of Climate Change", Oxford Institute of Economic Policy Distinguished Lecture, January 2006, redrawn from IPCC TAR http://www.hm-treasury.gov.uk/Independent_Reviews/stern_review_economics_climate_change/sternreview_index.cfm

[160] NASA, "GISS Surface Temperature Analysis - Global Temperature Trends: 1996 Summation" http://data.giss.nasa.gov/gistemp/1996/

## 2. Dangerous climate change

There are several opinions concerning the degree of warming that might be considered bearable: The EU has suggested that 2°C above pre-industrial levels should be the limit required to avoid dangerous changes[161]. This value was repeated by a more recent, in-depth study[162].

James Hansen, NASA's authority on the subject, has suggested 1°C is already too much while James Lovelock (proposer of the 'Gaia' hypothesis) believes that any increase at all is dangerous. Since the present level of increase (over the pre-industrial average) is 0.8°C[163], it seems that we may have little time left for mitigation or adaptation.

## 3. Natural Trigger Points for Abrupt Change

Feedback effects accelerate warming and increase the effects of climate change. One example is the acceleration of the flow of large glaciers in the Greenland Ice Sheet[164]. Increased surface melting leads to flows of meltwater to the base of the glaciers, lubricating their sliding over the base rock. Warmer ocean water and the loss of floating ice shelves also increase the loss of high-albedo ice from Greenland, raising the rates of both warming and sea level rise[165]. The Antarctic Ice Sheet is currently losing 150 cubic kilometres of ice per year[166]. Both the West Antarctic Ice Sheet and the Greenland Ice Sheet may melt at rates that result in sea level rises exceeding 1 metre per century[167]. A temperature increase of 2.7°C may trigger this[168].

These destabilising feedback effects may even lead to abrupt changes followed by an irreversable warming[169].

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[161] 1939th Council Meeting, Luxembourg, 25 June 1996, also discussed in "Winning the Battle Against Global Climate Change", Commission of the European Communities, February 2005 http://europa.eu.int/comm/environment/climat/pdf/comm_en_050209.pdf

[162] International Climate Change Taskforce, "Meeting the Challenge", 2005 http://www.ippr.org.uk/ecomm/files/meeting_the_climate_challenge.pdf

[163] Hennessy, K. & Fitzharris, B. "Climate change in Australia and New Zealand: Impacts, adaptation and vulnerability", Greenhouse 2005, 15th November 2005 http://www.greenhouse2005.com/downloads/program/GH2005_Presentation_200511150940_1.ppt

[164] Chen, J. L., Wilson, C. R., Tapley, B. D., "Satellite Gravity Measurements Confirm Accelerated Melting of Greenland Ice Sheet", Science, 2006, August 10, Science DOI: 10.1126/science.1129007
Arctic Climate Impact Assessment, "Impacts of a Warming Arctic: Arctic Climate Impact Assessment", 2004 http://amap.no/acia/

[165] Dowdeswell, J.A., "The Greenland Ice Sheet and global sea-level rise", Science, 2006, 17th February, Vol 311, No 5763, pp. 963-964
Bindschadler, R., "Hitting the ice sheets where it hurts", Science, 2006, 24th March, Vol 311, No 5768, pp 1720,1721

[166] Velicogna, I., Wahr, J., "Measurements of time-variable graity show mass loss in Antarctica", Science, 2006, 24th March, Vol 311, No 5768, pp 1754-1756

[167] Overpeck, J., Otto-Bliesner, B.L., Miller, G.H., Muhs, D.R., Alley, R.B., Kiehl, J.T., "Paleoclimatic evidence for future ice-sheet instability and rapid sea-level rise", Science, Vol 311, No 5768, pp 1747-1750

[168] "Avoiding Dangerous Climate Change - International Symposium on the Stabilisation of greenhouse gas concentrations", Hadley Centre, Met Office, Exeter, UK, 1-3 February 2005 http://www.defra.gov.uk/environment/climatechange/internat/dangerous-cc.htm

[169] International Climate Change Taskforce, "Meeting the Challenge", 2005 http://www.ippr.org.uk/ecomm/files/meeting_the_climate_challenge.pdf

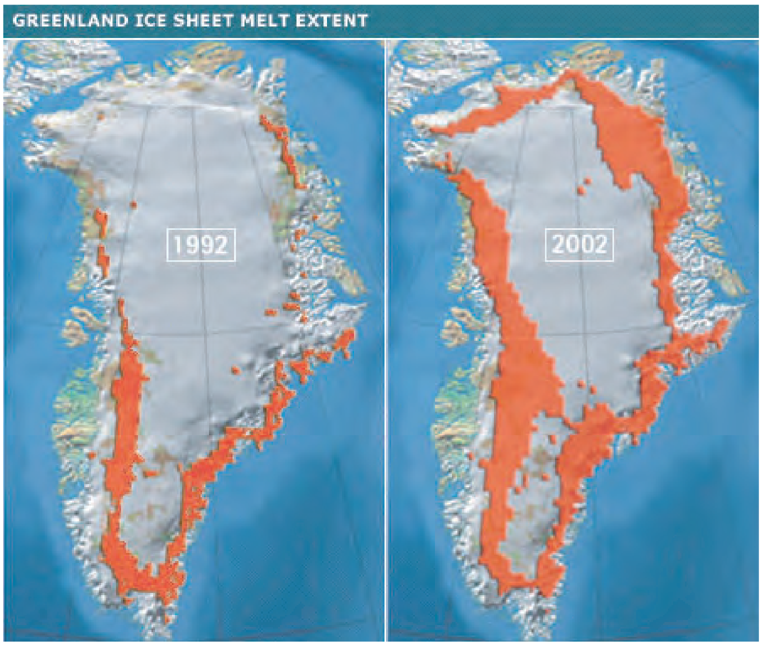


**Figure 11:** Areas where losses due to melting are resulting in thinning of the Greenland ice sheet in the 10-year period 1992-2002 are shown in red[170].
The extent of the north polar ice cap is also declining in a similar manner.

There are natural sources of $CO_2$ and $CH_4$ which cannot be controlled once certain thresholds are met: for example, forests and other large carbon sinks can become net sources of $CO_2$ when the mean regional temperature increase is about 3°C[171] (as observed during the European heat wave of 2003). The oceans and forests are the main sinks that we rely upon at present to keep the $CO_2$ level from growing at more than its current rate of 2.6 ppm per year. This is already rapid but the rate should be expected to increase substantially as more coal-fired power stations are brought into operation in growing economies.

There are vast quantities of carbon trapped in permafrost and pest bogs Warming will resulting in the release of increasing amounts of this carbon to the atmosphere[172]. Some of that carbon will also be released as methane, a much more potent greenhouse gas than $CO_2$. The ratio of the warming due to 1 ppm of methane to that of 1 ppm of $CO_2$ exceeds 100. Vast quantities of methane are also trapped as clathrates (i.e. in gas hydrides) in the deeper layers of the ocean and warming may release these, providing a further potential source of destabilising positive feedback[173].

## 4. The Consequences of Warming:

New Zealand has already been affected by climate change with the loss of a quarter of all glacial ice[174]. In the future, New Zealand will be less affected by climate change than other nations. We are surrounded by an ocean that keeps our temperature relatively even and there is no large land mass nearby which might tend to produce a 'continental' climate. Thus, according a range of climate models New Zealand should warm less than

[170] Abdalati, W. and K. Steffen, "Greenland ice sheet melt extent: 1979-1999", Journal of Geophysical Resources, volume 106, number D24, pp33,983-33,989, 2001 http://cires.colorado.edu/steffen/melt/gr_melt_88_02.pdf

[171] Scholze, M., Knorr, W., Arnell, N.W., Prentice, C., "A climate change risk analysis for world ecosystems", PNAS (Biological Sciences/Environmental Sciences) published online 14 August 2006.

[172] Zimonv, S. A., Schuur, E.A.G., Stuart Chapin III, F., "Permafrost and the global carbon budget", Science, 2006, 16th June, Vol 312, No 5780, pp 1612-1613

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[174] Hennessy, K. & Fitzharris, B. "Climate change in Australia and New Zealand: Impacts, adaptation and vulnerability", Greenhouse 2005, 15th November 2005 http://www.greenhouse2005.com/downloads/program/GH2005_Presentation_200511150940_1.ppt

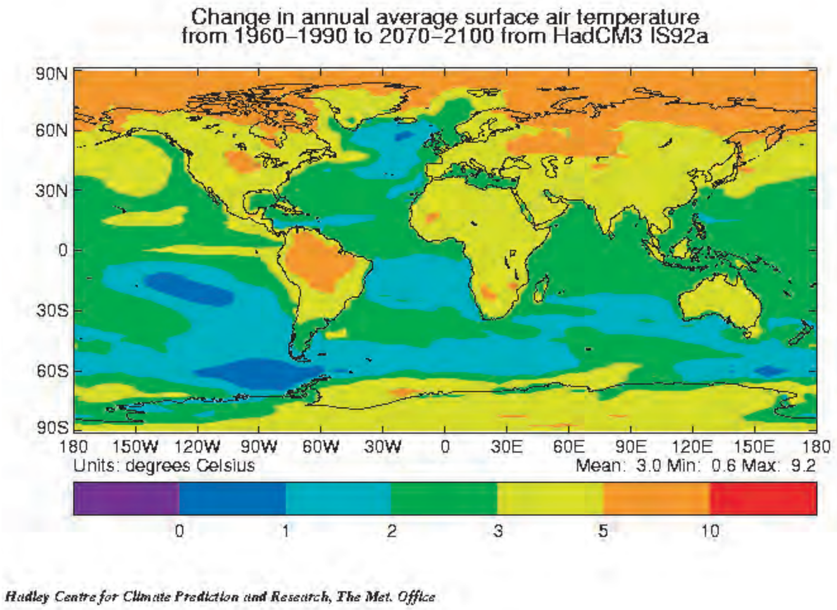


**Figure 12:** A simulation of the distribution of the annual temperature anomaly relative to the level of 1960-1990, corresponding to a global mean temperature rise of 3°C (Hadley Centre, UK). Local changes vary from 0.6°C to 9.2°C.
The greatest effect (5-10°C) occurs at high latitudes, particularly in the Arctic. New Zealand, in contrast, warms only by about half the global mean anomaly (1-2°C) while most other areas warm by 3-5°C. This pattern is consistent with present observations.

the global mean temperature increase[175]. However, New Zealand is likely to experience more frequent and more severe droughts in the east[176], more rainfall in the west, more frequent heavy rain and higher peak intensity of rainfall, increased sea level and increasingly strong westerly winds[177].

However *mean* temperature increase does imply that the temperature anomaly is *uniformly distributed*: for example, in normal conditions, the climates of countries at the same latitude may differ substantially (cf. New Zealand and Spain). If the mean global increase is 3°C, then sub-Arctic regions and the US prairies and Brazil will suffer an increase of 5-10°C, and most of Africa, Europe, Asia and Australia about 3-5°C. (Without feedbacks and for periods of a few decades, the temperature response according to the Hadley simulations is almost linear so that for global mean increases of 1 or 2°C, these ranges should be scaled by 1/3 or 2/3 respectively.) It is already clear that the average temperature has increased by about 3°C in Siberia and high latitudes which has led to noticeable melting of permafrost and the Arctic ice cap (Figures. 7,11).

The most obvious effects of warming are apparent where physical phase changes occur such as ice to water (melting glaciers), liquid water to water vapour (hurricanes and typhoons) and especially in locations where the local climate is already on the verge of serious drought such as East Africa.

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[175] Mullan, A.B.,Wratt, D.S., Renwick, J.A., "Transient model scenarios of climate changes for New Zealand", Weather and Climate, 2001
US Climate Change Science Program, "Temperature Trends in the Lower Atmosphere: Steps for Understanding and Reconciling Differences", Synthesis Product 1.1, April 2006, which refuted concerns over satellite temperature record anomalies.
www.climatescience.gov/Library/ sap/sap1-1/finalreport/default.htm
Steffen, Will, "Stronger Evidence but New Challenges: Climate Change Science 2001-2005", Australian Greenhouse Office, Department of the Environment and Heritage
http://www.greenhouse.gov.au/science/publications/science2001-05.html
Levin, K., Pershing, J., "Climate science 2005: Major new discoveries", World Resources Institute, 2005

[176] Mullan, B., Porteous, A., Wratt, D., Hollis, M., "Changes in drought risk with climate change", NIWA Client Report: WLG2005-23 May 2005
http://www.climatechange.govt.nz/resources/reports/drought-risk-may05/index.html

[177] Wratt, D., Mullan, B., Salinger, J., Allen, S., Morgan, T., Kenny, G., "Climate Change Effects and Impacts Assessment: A guidance manual for Local Government in New Zealand"
http://www.climatechange.govt.nz/resources/local-govt/effects-impacts-may04/index.html

## Consequences for New Zealand

Waming is accompanied by increased evaporation of water vapour from the oceans, which results in increased precipitation of rain and snow. The extra rain does not necessarily fall on drought-stricken regions but onto the ocean, onto areas already subject to high rainfall (monsoons) and as extra snow in polar regions and on high mountains. The snow helps balance the loss of ice from the margins of the polar ice caps, ameliorating to some extent the rise of sea level. It also replenishes those glaciers that are not already retreating rapidly (as in New Zealand recently and in Norway for example).

The overall expected changes in precipitation is very negative in that present drought-stricken regions can only suffer more Even in relatively optimistic models, rainfall in South Africa, the Horn of Africa, other sub-Saharan regions is expected to drop by 10%, leading to drops in surface drainage of up to 80% [178]. This may render parts of these areas uninhabitable. Australia, the southern States of the USA and even southern Europe are problematic. The current emergency in Somalia, Kenya, Eritrea, Dafur and other countries in the Horn of Africa are not simply the result of a chance drought exacerbated by political, religious and ethnic differences. The root cause has been climate change, which has led to a persistent loss of water, stock and crops, with consequent starvation. This may rapidly drive migration from the worst hit areas, including Asia and the Pacific[179], to more favourable places – but where?

The direction of changes in New Zealand are well understood; the magnitude of changes less so.There should be increased precipitation, up to 40% more by 2080, on the West Coast, particularly in Fiordland[180], and a tendency for more frequent and intense droughts[181] to occur in currently dry regions such as eastern Canterbury, coastal Marlborough, Hawke's Bay and Poverty Bay[182]. We would need to develop means to deal with the associated redistribution of our water resources. There will also be increasing pressure for migration from less favourably affected countries and this will not be easy to handle. For this reason, population growth and the capacity of the country to absorb and support more inhabitants are matters for serious concern.

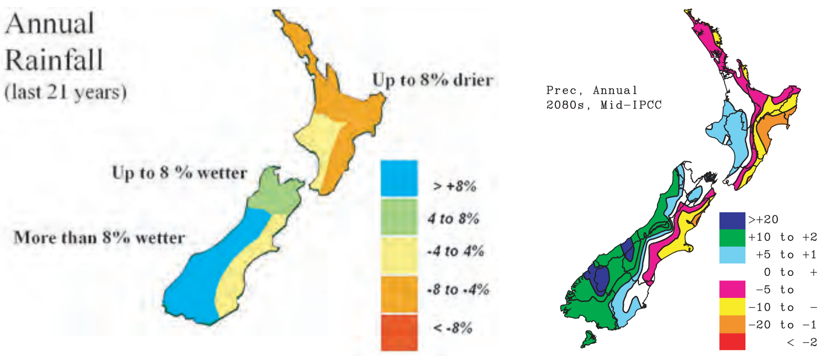



**Figure 13:** Percentage changes in the annual precipitation during the past 21 years (above) and predicted for the late 21st Century[183].
Precipitation has increased in the west and decreased in the east, as expected from our understanding of the effects of global warming, and that this will become more pronounced as time goes on.

[178] de Wit, M., Stankiewicz, J., "Changes in surface water supply accross Africa with predicted climate change", Science, 2006, 31st March, Vol 311, No 5769, pp. 1917-1921

[179] DuPont, A., Pearman, G., "Heating up the planet – Climate change and security", Lowy Institute Paper, Number 12, 2006

[180] Wratt, D., Mullan, B., Salinger, J., Allen, S., Morgan, T., Kenny, G., "Climate Change Effects and Impacts Assessment: A guidance manual for Local Government in New Zealand" http://www.climatechange.govt.nz/resources/local-govt/effects-impacts-may04/index.html

[181] Mullan, B., Porteous, A., Wratt, D., Hollis, M., "Changes in drought risk with climate change", NIWA Client Report: WLG2005-23 May 2005 http://www.climatechange.govt.nz/resources/reports/drought-risk-may05/index.html

[182] Hennessy, K. & Fitzharris, B. "Climate change in Australia and New Zealand: Impacts, adaptation and vulnerability", Greenhouse 2005, 15th November 2005 http://www.greenhouse2005.com/downloads/program/GH2005_Presentation_200511150940_1.ppt

[183] New Zealand Climate Change Office, "Climate Change Effects and Impacts Assessment: A guidance manual for Local Government in New Zealand", May 2004 http://www.climatechange.govt.nz/resources/local-govt/effects-impacts-may04/index.html

Climate change will cause more frequent extreme events and harsher extreme events. There has been an increase in the frequency of intense (categories 4 and 5) hurricanes during the last 20-30 years as a result of higher sea-surface temperatures in many parts of the world[184]. New Zealand will not be spared such events.

Sea level rise is a serious matter, especially for low-lying islands and reclaimed coastal regions. The expected rate of increase may be as high as 10 cm/decade[185]. Sea level rise also varies across the globe and in New Zealand has occurred at 1.6 mm/yr over the last hundred years[186]. Some coastal regions of New Zealand will suffer from the combination of modest sea level rise and increased storminess (e.g. Haumoana in Hawkes Bay). Our coastal plains, which have been built up by deposits of shingle from rivers, will build higher shingle beaches. River water will tend to pool in the flat ground behind the beaches and will have to be controlled by higher stop-banks (this may be an advantage in terms of water supply).

## 5. 'Natural' Mitigation of Warming:

There are many natural sources of greenhouse gases that cannot be controlled. For example, methane is emitted from naturally-occurring and widely-distributed peat bogs, permafrost and deep ocean clathrates as well as from man-made sources such as paddy fields and landfills.

Atmospheric methane has a relatively short half-life in the atmosphere (about 10 years). It should be possible for a significant decrease in the atmospheric content of methane to take place quite quickly if any of its major sources can be eliminated. For this reason it is attractive to deal with the emissions from ruminants which constitutes about one half of New Zealand's greenhouse gas problem. There are possible solutions under trial, however most international work involves housed animals and is not relevant to New Zealand unless we also adopted housing our cattle.

Nitrous oxide is a potent greenhouse gas and is largely associated with the application of agricultural fertilizers. Its half-life in the atmosphere is about 120 years. Emissions can be reduced by eliminating the use of nitrogen-based fertilizers and certain industrial processes and by the use of nitrification inhibitors.

Atmospheric carbon dioxide is the longest-lived major greenhouse gas and in the short term can be regarded as simply accumulating indefinitely except for losses associated with photosynthesis and absorption in the oceans. These control the $CO_2$ half life (>100 years) but with increasing temperatures they are unreliable for the reasons outlined above. Similarly, if the sea surface temperature becomes too high the dissolved $CO_2$ is released as from warm soda - however $CO_2$ in the form of carbonic acid should remain fairly stable.

As is the case with $CH_4$, large amounts of $CO_2$ are trapped in the form of a clathrate hydrate in the deep oceans and lakes. Provided there is no disturbance – due to warming for example – it should stay there.

Forests and vegetation offer the most secure possibility for the sequestration of $CO_2$. However, although re-forestation should be pursued actively, it may be limited in its effectiveness if the temperatures become so large that emission from the ground exceeds

[184] Hoyos, C.D., Agudelo, P.A., Webster, P.J., Curry, J.A., "Deconvolution of the Factors Contributing to the Increase in Global Hurricane Intensity", Published Online March 16, 2006, Science DOI: 10.1126/science.1123560
Webster, P.J., Holland, G.J., Curry, J.A., Chang, H.-R., "Changes in tropical cyclone number, duration and intensity in a warming environment", Science, 2005, September 16, Vol 309, No 5742, pp. 1844-1846
Emanuel, K., "Increasing destructiveness of tropical cyclones over the past 30 years", Nature, 2005, August 4, Vol 436, No 7051, pp. 686-688

[185] Hennessy, K. & Fitzharris, B. "Climate change in Australia and New Zealand: Impacts, adaptation and vulnerability", Greenhouse 2005, 15th November 2005
http://www.greenhouse2005.com/downloads/program/GH2005_Presentation_200511150940_1.ppt

[186] Hannah, J., "An Updated Analysis of Long Term Sea level Change in New Zealand", Geophysical Research Letters, 2004, Vol 31,

the absorption by photosynthesis. It will also be affected by warmer temperatures and changed rainfall distribution. Furthermore, forests take time to be established and might not be sufficiently developed in the time remaining before irreversible greenhouse warming sets in. There are also affected by the extreme weather events that climate change causes. For this reason, forestation might not save the day. In any case, the area of new forest required to make a significant impression on the 5-10 billion tons of $CO_2$ emitted globally each year is enormous, possibly "equivalent to an area about the size of France in low latitudes and Germany in temperate regions, every year from 2010 to 2035"[187]. This may be unachievable.

## 6. The Future

Recent simulations made by the Hadley Centre suggest that the global mean temperature is likely to rise by about 3°C which corresponds to the distribution of temperature anomalies shown in Figure 12[188]. This is within the range of 1.4 to 5.8°C by 2100 predicted by the IPCC[189]. This would result in the loss of half of the world's wildlife reserves, the destruction of major forest systems and put at least 400 million people at risk of hunger. The estimate does not take into account feed-back processes such methane release, albedo changes and quenching of forest and oceanic $CO_2$ uptake and is therefore rather optimistic. The date at which this should happen is also uncertain since it depends on the intervening emission profile of greenhouse gases as well as the effects of feed-backs. In any case, the prognosis is not favourable.

We in New Zealand will not suffer directly as much as many other countries in the course of such a temperature rise. However we will suffer indirectly because we depend so much on trade and tourism which will be seriously reduced. Thus it is in our interest to behave in an exemplary way in terms of eliminating additional greenhouse emission which can be achieved by

- eliminating our dependence on imported fossil fuels, in particular by the introduction of biofuels;
- reducing the production of methane by ruminants;
- avoiding the use of coal and other fossil fuels in power plants unless the $CO_2$ emissions are adequately sequestered;
- striving for energy savings and efficiency wherever possible; and
- controlling our growth in a manner consistent with our resources.

It is evident that such measures will have to involve both regulation and fiscal measures. Our transport system should be made more efficient, particularly in the public sector. This and our vehicle fleet should evolve with the introduction of biofuels.

With such measures we would be doing almost as much as is reasonable in comparison with other countries. More advanced technologies such as hydrogen cells, which require an independent energy source (e.g. hydroelectric), must wait until they are well-developed elsewhere. The manufacture of biofuels, reducing emissions from ruminants, fossil-fuel free electricity generation and making better use of the electricity that we do generate are clear steps that we must take.

[187] Read, P., Parshotam, A., "Holistic greenhouse gas management", Department of Applied and International Economics, Massey University, 2005

[188] HM Treasury "Stern Report - What is the Economics of Climate Change?", Discussion Paper, January 2006 http://www.hm-treasury.gov.uk/media/213/42/What_is_the_Economics_of_Climate_Change.pdf

[189] IPCC "Third Assessment Report – Working Group I: The Scientific Basis", Section F.3 "Projections of Future Changes in Temperature", 2001 http://www.grida.no/climate/ipcc_tar/wg1/index.htm

# RECOMMENDATION VI
# ENERGY RESEARCH

That New Zealand must undertake a sustained effort to drive indigenous innovation to address systemic energy and environmental issues. Substantial collaborative research and development is required and must involve the spectrum of industry, community, government and research.

VI. 1. New Zealand's energy problems must be solved for New Zealanders by New Zealanders.

VI. 2. Demand side management for electricity and transport, energy efficiency uptake, carbon capture and secure sequestration technology, biomass refining technology, coal and biomass gasification technology and hydrogen technology all stand out as research areas pivotal to New Zealand's energy future.

VI. 3. We have the skills and capabilities to import many existing energy technologies, including biorefining and gasification technologies, to adapt them and then to export these adaptations to others.

VI. 4. We have scientific, technological and engineering skills but to solve many of our energy problems we will need to unite scientific and commercial endeavours. In particular, New Zealand scientists and engineers have proven expertise and international leadership in geothermal generation development, and recognize specific areas for ongoing research and development.

VI. 5. We need to grow New Zealand's energy science, technology and engineering capabilities through focusing on the tertiary education sector as energy solutions will be a long term quest. New Zealand needs an expanding capability in energy research, development and deployment.

VI. 6. The research and development thrust in constrained system engineering, management, social adaptation, market development and transformation, and economics represents an opportunity for growth based on innovation.

VI. 7. Research on options for New Zealand's future transportation systems should be integrated with other energy research. The primary needs include: alternatives to on-demand mobility; systems for better planned access to services and markets; advances in information systems; urban design; freight organization; adaptation to a renewable energy transportation system; land use implications of large scale biofuel production systems.

VI. 8. Turning our creative efforts toward responding to the constraints of the twenty-first century will help New Zealand to provide services far into the future. Key operational research themes include: behavioural and cultural influences on energy demand; factors influencing the deployment of more energy efficient systems; land use and large scale renewable energy activities; health issues linked with energy use and energy related emissions; tradeoffs involved in developing new forms of energy; economic, structural and legal aspects of energy use and energy management; distributed energy systems, including energy provision for isolated communities and for the disadvantaged. Advances and discoveries made will have ready markets overseas as both developed and developing countries will have to deal with their own energy supply security and carbon emissions targets.

VI. 9. We need to build New Zealand's adaptive capability through a focus on research and innovation in new technologies, smart systems, modelling and economic instruments which can be deployed to manage regimes of constrained energy supply and/or capped greenhouse gas emissions.

VI. 10. New Zealand must have top-quality and transparent research-based foresight capability to inform long-term energy and environmental policy development, strategic planning, long-term infrastructure investment, and the transition to renewable energy transportation and electricity systems. For these purposes New Zealand needs to build its capacity for energy systems modelling and scenario-building to anticipate its future on a 50 year time scale in an ongoing way. This capacity should be supported by research in relevant engineering, scientific, resource, economic, health and social disciplines.

VI. 11. Energy research and development now receives public-good funding of approximately $17 million per annum. Research on petroleum and coal resources had received by far the greatest share of energy funding. Such an important area as energy, and renewable technologies, should receive more than a small fraction of the public-good research funding and this year's budget increases are but a tiny step in the right direction[190].

VI. 12. Revenue from future carbon charges and windfall profits from high oil prices should be put towards funding energy education, research and development.

VI. 13. Given the scale of the problem of developing renewable energy resources, a significant funding investment is essential with an entirely different set of processes to mobilise multidisciplinary teams across scientific institutions.

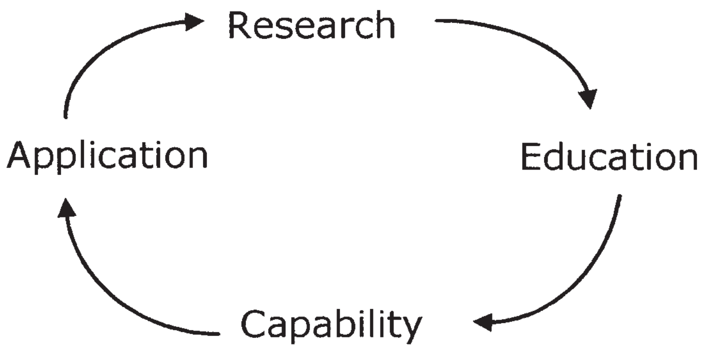
VI. 14. To ensure renewable energy and economic security progress we recommend that an Energy Taskforce be set up, with a budget to drive the development and implementation of efficient and renewable energy technologies. The Taskforce must ensure our capacity in energy research, development and deployment. Universities need support to seed that capability; CRIs need support to develop and apply that capability. The Taskforce will also drive the analysis of the behavioural changes that face society and the analysis of what sustainable energy sources imply for society, issues often ignored in developing and implementing significant technological change.

[190] IEA" Energy Policies of IEA Countries – New Zealand", 2006

## BACKGROUND TO ENERGY RESEARCH

### 1. Strategic Role of Research

Addressing our energy issues and developing towards sustainable systems will rely heavily on a learning culture. An adaptable, curious culture, with vigorous research capability and rapid exploration of new opportunities will be able to evolve its technology, behaviour and activities to deal with energy and resource constraints and carbon emissions limits. A necessary aspect to an adaptable culture is established and engaged research. All research contributes to education and capability in a positive cycle:




The nature of research activity depends on the maturity of the technology and the state of the scientific knowledge.

Category I. technologies like household appliances are built domestically and overseas. Use of these appliances in NZ's energy system may lead to new problems and new ideas. For example, the evening power demand peak in Christchurch is a grid constraint problem, hence if the grid behaviour of "smart appliances" could respond to signals about the grid state, then it could delay operation until after the peak without loss of service.

Category II technologies include ideas such as fuel cells, hydrogen storage, $CO_2$ sequestration, and superconductivity. Category II research has the same educational benefits, however, it may involve more fundamental scientific research in areas like materials science, chemistry and fluid dynamics.

Important areas of Category II research are feasibility, lifecycle cost, sustainability and system integration of such technology ideas as bioethanol. With modelling done on a system level, a picture of the reasonable opportunities for application can be provided and resources for development allocated efficiently.

| Technology Status | Research Activity |
|---|---|
| I. Mature Technology<br>(Available domestically & overseas) | Application in New Zealand,<br>Operational research, System integration and system effects, Product improvements, Sustainability |
| II. New Technology<br>(Ideas and science mature, but Technology not yet commercial) | Adaptation, Product development, System integration and system effects, Sustainability, New applications, Feasibility and impact modelling |
| III. New Zealand Problem Definition<br>New Zealand Perspective | New systems, New science, New technologies,<br>New management, New networks, New modelling,<br>New engineering methods and design |

Category III technologies may not have been conceived yet because the questions have not been asked and the problems have not been posed. New Zealand may be first developed country to have to face the problem of constrained energy resources. Innovations to deal with problems cannot be realized if the brightest minds in the country are not focused on these problems and asked to find solutions.

Policymakers, consumers and business people can all benefit from research at these varied levels and carrying out that research is an essential part of maintaining and growing a capability to address energy issues.

## 2. Policy and Operational Research

A range of policies are available to minimise the expected impacts. Many of these policies are politically unpalatable and of uncertain effectiveness. We need effective policy so we need better understanding of the effects of policy on a strategic level. This will require a major investment in policy and operations research, as called for by other groups[191]. An example of the policy questions that need to be answered on a global level is presented in Gielen and Unander's paper. A national version of these questions is a priority[192].

## 3. Biofuels Research

Today, the use of plant feedstocks is a step in a positive direction to use solar energy to meet our energy needs. Tomorrow this will undoubtedly expand to include photovoltaics and hydrogen production from ethanol and water.

The growth in New Zealand of a lignocellulosic biorefining industry producing ethanol on a large scale has clear processing components where basic and applied work on improvements will lead to clear cost reductions. There are four major steps, all commercially used today, but which through the next decade will see cost efficiencies that petrol is not likely to compete with.

First, cellulose is a more difficult substrate for bioconversion as compared to sugar from sugarcane and starch from corn, and large amounts of enzymes are required to reduce cellulose to sugar. Second, lignin contains polysaccharides and inhibits enzymatic hydrolysis of these carbohydrates; energetically expensive and corrosive chemical pre-treatments are required for its removal from corn stover, and softwood feedstocks. Third, the yeast currently used in large-scale ethanol production cannot efficiently ferment sugars other than glucose. Relatively low concentrations of ethanol kill these microorganisms, requiring an expensive separation of the product from large volumes of yeast growth medium. Fourth, hemicellulose is made of C5 sugars and previously has been difficult to use as a substrate for conversion the ethanol. There are now yeast strains which have had the biochemical pathway for fermenting C5 sugars engineered into them. Such yeast strains allow the choice as to whether to use, for example, xylose to produce more ethanol, or to diversify to use the xylose to produce xylitol as a food sweetner.

There is a great deal of international work in these areas and this has resulted in the lowering the costs of converting biomass to ethanol already in the past decade. We will benefit most from participating in international research into lowering the cost of lignocellulose conversion of crops suitable for domestic growing conditions and processed using geothermal heat.

New energy crops will be developed with improved rates of growth and suitability for fuel and other product development. Sustainable farming methods will be increasingly sought and New Zealand with its agricultural background is well-suited to be a major participant.

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[191] IPENZ, "Energy Policy – Engineering a National Energy Strategy", 2006 http://www.ipenz.org/IPENZ/Media_Comm/documents/EnergyDoc.pdf

[192] Gielen, D., Unander, F., "Alternative Fuels: An Energy Technology Perspective", IEA/ETO Working Paper, March 2005, http://iea.org/textbase/papers/2005/ETOAltFuels05.pdf

Urgent research is needed to understand the compatibility with biofuels of the aged domestic vehicle fleet. Newer vehicles are biofuel capable, but corrosion problems may occur with older Japanese imports. We do not know how large a problem this will be. Japanese importers have no current incentive to resolve this problem in a definitive manner. If the Government wishes to support the introduction of biofuels blends higher than 5%, this question must be addressed.

Production of hydrogen, butanol and other fuels by biological routes offer another potentially large source of energy and deserve continuing investigation.

## 4. Oil and Gas Exploration

Approximately 50% of the Public Good Science Fund (PGSF) funds has historically been distributed to oil and gas exploration in support of commercial exploration activities. The funding has predominantly gone to basin evolution and petroleum systems potential research: collation of regional and basinal petroleum potential, rather than prospect-specific investigations.

Government also effectively contributes to oil and gas research through the activities of Genesis Energy, co-venturer in the Kupe South development and one small onshore exploration prospect, and Mighty River Power, which has an active exploration programme with Swift Energy.

Government funding of oil and gas research is basically aimed at stimulating and supporting exploration activities, whilst maintaining exploration capabilities in the country. Increasingly, regional studies are used to support "Blocks Offers". Four areas that future research needs address are:

- Improved information and analysis of reservoirs, including production performance and hydrocarbon characterization.
- Enhanced recovery techniques
- Regional studies of frontier basins (to stimulate exploration activities)
- Specific database projects (core analysis, drilling mud, formation waters and drilling parameters).

Gas hydrates is a long-term future potential hydrocarbon source and preliminary research indicates the East Coast of the North Island has significant potential for gas hydrate reserves. Japan and Canada currently lead extraction technology research and New Zealand should seek to leverage its own limited research against these efforts.

## 5. Solar Energy

Making ethanol, from crops, as a bio-fuel is an efficient use of solar energy. It is a first step, however. The next step is to use sun energy directly. The amount of energy hitting the earth from the sun is tremendous = 100,000 TW (1 TW is equivalent to 1000 nuclear reactors at the present technology). A very conservative estimate puts the practical amount equal to 500 TW (which is still far higher than the present world demand in energy of about 15 TW/annual on average).

Solar energy can be harnessed in three principal but different ways: direct use/passive solar heating, solar hot water and photovoltaic arrays. Because they are different, the needs for research into each are different.

Direct use/passive solar heating is a minimum technology approach, with well understood capabilities, but research may be needed to understand how to increase the uptake of this low risk, low cost approach.

Solar hot water systems are low technology heating systems, based on plumbing, intended for domestic or small-scale installations. The principal contribution to supply/demand is the ability of SHW to offset peak electricity demand. SHW technologies are mature with recent developments focussed on energy capture. New Zealand is a technology taker, utilizing technologies from Europe, Israel and Australia, although there are manufacturers in New Zealand, such as Thermocell and Solar60.

Two principal issues with SHW technologies are the capital cost of equipment and the unit cost of energy. Reduction in equipment costs is thus a key theme for research. Scaling up systems from domestic to commercial building scale also has potential. The measurement of performance and standard-setting are also areas for research. Since the majority of SHW systems are plumber-installed, education programmes for their promotion and installation are justified.

Photovoltaic (PV) arrays currently make a contribution, particularly in small, remote, off-grid applications, such as electric fences, road signs, telecommunications towers. Although the worldwide PV market has grown at around 30% per annum in recent years, most of the growth has been in domestic-scale applications. High-temperature and large-scale systems are only economically viable in low-latitude countries with much higher solar insolation. In New Zealand, the solar resource is too small to be attractive at anything much greater than the domestic scale, although some small commercial applications have been installed (e.g., BP service stations, MainPower's head office in Rangiora).

A key technical issue is low efficiency (7 – 14 %) and heat buildup, which reduces electrical conversion efficiency. Current flat-plate silicon systems are being replaced by thin-film systems and photo-synthetic systems.

Most PV system research is being conducted in Germany, Japan, Australia and China, but collaborative research to reduce capital costs and increase efficiency may offer opportunities in New Zealand. Government should consider offering incentives for domestic installations, as has been successful in Germany and the US, to reduce domestic electricity demand.

## 6. Hydrogen

Hydrogen is the best burning chemical compound known. Its burning efficiency (51,000 BTU) is about five times higher than ethanol (10,000BTU) and over two times higher than methane (21,000 BTU). The main limiting factors are: (i) making hydrogen from renewable sources (such as ethanol) with a positive energy balance (positive in this term means the energy obtained at the end of the complete process should be better than that obtained from directly burning ethanol), (ii) storage and transportation of hydrogen, (iii) finding alternative technologies.

(i) Because the internal combustion energy efficiency is about 0.3 and that of a fuel cell to generate electricity from hydrogen is higher (up to 0.9), an optimistic margin for reforming (which is an energy demanding process) of ethanol to hydrogen is present. On board reformer and fuel technology, where ethanol can be converted to hydrogen is an attractive option for stationary power generators.

(ii) Hydrogen is the lightest molecule on earth. This causes severe limitations on its use. Compression technologies are mature and available but they add considerably to the cost. Other promising technologies are based on solid materials that can store and release hydrogen. While this research is in its beginning it will ultimately result in a considerable improvement of the hydrogen-transport cycle.

(iii) Alternative technologies include using sunlight to make hydrogen from water as well as renewable sources like ethanol. This solar hydrogen can be produced by driving water electrolysis with solar cells, by direct photo-catalytic water splitting into hydrogen and oxygen, by photo-biological water splitting, or by solar thermal processes. A large number of researchers worldwide are currently involved in these processes. At present materials to make hydrogen from water with 50 % conversion of UV light are available. This is not yet practical because a small fraction of the sunlight is in the UV spectrum. Efforts are now conducted to design materials that can absorb visible light (most of the sunlight spectrum on earth). In addition, the potential for making hydrogen from bio-fuel using sunlight might be attractive as a supplementary route to the present reforming technology (in itself in the R&D phase).

## 7. Nuclear

Nuclear energy is not a viable option for New Zealand at present and in the near future. However, nuclear technology can meet the present and future energy demand for the world. Raw materials for nuclear fuel are widely available (equivalent to 400 TW using conventional nuclear reactors). While NZ is a nuclear free country, it might be wise (given the high potential of nuclear technology to solve the present and future energy-demand problem) to consider research in both nuclear fusion and fission, at the educational level. In case New Zealand considers nuclear technology in the future, scientifically and technically educated personnel would be available to evaluate the technology consider the options, and make the transition less severe.

## 8. Transport Systems Research

We do not know how to make large cuts in transport energy use at an acceptable social and economic cost. We do not know how to cope with substantial supply shortages at a minimum cost. And yet we may need to take these steps.

## 9. Zero-carbon Electricity Research

### Renewable Supply

Our wind resource is now well characterised at a coarse level; our marine resources are not, yet they have the potential to be much larger. We will also need to understand the environmental and social impacts of marine developments to avoid the kind of concerns that hinder wind energy development.

Most renewable sources are variable and as renewable generation grows, we will need research to better predict output and to better match variable supply with variable user demand.

### Marine Generation

Marine energy can be divided into wave and tidal energy. Wave energy can be extracted either from breaking waves or passing offshore swells. Early technologies relied on the former but have met with limited success. The focus has now moved to offshore technologies, which seek to extract energy from the passing swells. The first commercial technology, Pelamis, derives energy in this way. There is currently a proliferation of other technology concepts. It is likely that a small number of niche application technologies will develop, which will operate in different conditions and extract energy in different ways.

Tidal technologies range from tidal barrages and impoundments, acting as low-head hydro systems, created by tidal rise and fall, to tidal stream turbines, which extract energy from passing currents. Tidal technologies have lagged behind wave technology developments but may surpass them, since tidal stream conditions are more constant and predictable than wave environments.

Whilst New Zealand has exceptionally good wave resources, its tidal resources are limited by the relatively low tidal range (2-3 m) and thus low average tidal current speeds. Potential sites for tidal energy extraction are thus more limited and patchily distributed. However, there has been a lack of physical measurements (most resource assessments are derived from satellite observations and hindcast studies) and few regional or site-specific assessments. Marine energy testing centres have been established in the United Kingdom, Ireland and Portugal and these centres have stimulated device deployments. The establishment of such a centre in New Zealand would be a stimulant to marine device deployments here. Further Government investment in domestic device designs can be justified on the basis that there is no dominant design for marine energy devices, nor is there an established industry worldwide. New Zealand has the benefit of a number of nimble niche industries with a marine background, such as those that came together for the 2000 and 2003 America's Cup challenges and those that support oil and gas exploration and exploitation in Taranaki.

**Wind Generation**

The wind industry is growing rapidly in New Zealand. The first turbine was constructed at Brooklyn in 1993 and two wind farms (Hau Nui and Tararua Stage 1) became operational in the 1990s. The 90 MW Te Apiti wind farm more than doubled the total national capacity when it came on stream in 2004 and there are now over 1,000 MW of capacity being constructed or going through the consent process. It is likely that the large number of sites currently being monitored will more than double this amount.

Wind energy is firmly established as a commercial (if still somewhat marginal) investment in New Zealand. The simplicity of prospecting for wind sites and the maturity of large-scale wind turbine technologies is such that the need for further research into site-specific resources and technologies is arguably limited.

Further research is justified, however, into regional resource measurements and modelling the centralized and real-time management of wind turbines feeding into the transmission system. Research into small-scale, off-grid turbine technologies and their integration with storage technologies is justified. Such technologies may have applications in remote parts of New Zealand and, through NZAID, in Pacific Island states.

**Geothermal Generation**

New Zealand is recognized internationally as having geothermal resources potentially able to meet 25% of near-term electrical power needs - perhaps more with deep drilling[193]. New Zealand has a strong history in geothermal development. In considering future geothermal research it is important to retain strong industry linkages to ensure research targets are compatible with industry needs and to maintain the experience necessary to support the industry.

Cost and risk reduction for geothermal development comes from understanding of below-ground resources, so sustaining and developing education and research resrouces results in cost-savings for the industry.

Although New Zealand currently exploits many of it higher temperature resources (typically between 130 and 300°C), research is required to exploit higher temperatures which exist beneath existing resources where infrastructure is already in place. Little attention has so far been given to lower temperature utilisation through direct use of geothermal for process heat and steam, and the use of ground source heat pumps for domestic or district heating. These lower temperature resources could greatly expand geothermal energy production.

**Microgeneration or distributed generation**

Distributed generation is low risk, provides resilience, especially for rural communities, allows for incremental investment and reduces grid dependence and load. Distributed generation could be encouraged as regional energy generation becomes more popular and electricity distribution companies are able to profitably invest in generation assets. (Distributed heating such as for solar water should also be considered with generation in terms of "distributed energy".) There is potential for increases in efficiency of thermal generation through the use of localized dual heating/power systems (such as provided by Whispergen, diesel/biodiesel gensets or gas engines).

The distributed generation industry uses a wide range of technologies but is constrained by a lack of industry capacity and a lack of skilled, experienced engineers.

This highly cross-disciplinary nature of microgeneration may put barriers in the way of funding for microgeneration technologies. For example, passive solar design provides

193 IEA review "Energy Policies of IEA Countries – New Zealand", 2006

low-technology and zero-cost heating and cooling and thus can reduce our nations' energy demand. However, research into its implementation and uptake affects the building industry, not the energy industry. Many other technologies involved in microgeneration could fall into gaps between scientific areas or between industries.

**Demand Side Management and Efficiency**

Many cost-effective energy efficiency steps are not being taken, both residentially and industrially. Our understanding of the social drivers that affect energy efficiency decisions is weak, and correspondingly our attempts to improve energy efficiency are not effective enough.

Our electricity system does not provide strong energy security. An energy securities market should resolve this, if it operated effectively. However, our ability to design economic tools to resolve policy problems is limited, as shown in the radio spectrum rights sell-off, where poor auction design resulted in a loss of hundreds of millions of dollars. We need better understanding of demand side management and its potential system impacts.

There is a need for social research to understand the difficulties of changing consumer behaviour and the impacts of that behaviour. Availability of technologies affects impacts without necessarily affecting choices. For example, minimum energy standards for appliances allow markets to work without overt interference to protect public goods.

**Beyond Coal**

The Government currently funds research (through FRST and Solid Energy) into coal gasification for the production of hydrogen and understanding of coal as a source rock for both oil and gas. Whilst New Zealand's coal resources are reasonably well understood, reserves of high-quality coal are not high. Use of coal has doubled in recent years due to increased use of coal at Huntly power station, although most of this coal is imported.

Both of the research themes listed above do not involve the combustion of coal and the consequent production of greenhouse gases. Whilst it is possible that further coal-fired generation plants may be built, New Zealand should extend its research into understanding of coal composition to improve combustion performance, gas production, volatile outputs and heating value. New Zealand should also continue its participation in international clean coal technology research and development, particularly utilizing domestic coal.

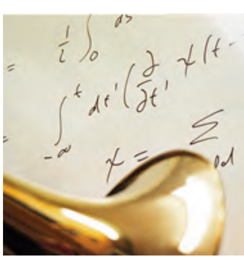
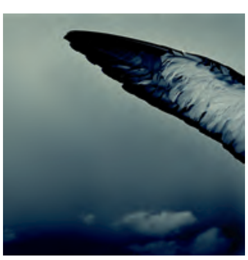
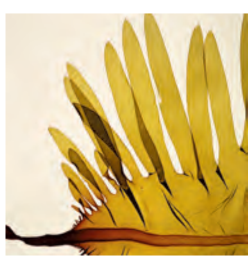
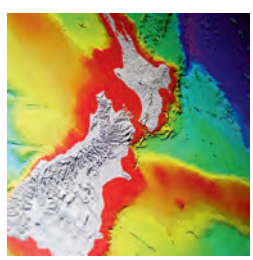
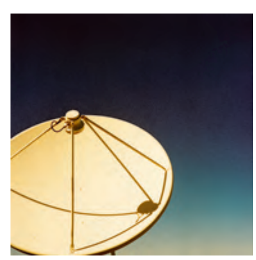
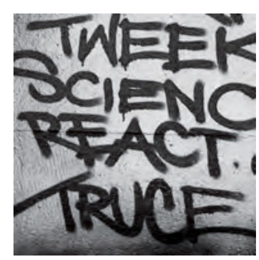
If we can find ways to use our low-quality coal without releasing carbon dioxide, then New Zealand will assure its energy future. Secure, affordable carbon capture and sequestration would allow us to use our coal reserves in an environmentally acceptable manner. These reserves are vast and can be expected to last hundreds of years. Thus we should continue to research CCS and remain closely connected to international work on sequestration. These must be investigated further but our energy strategy should not depend upon future outcomes of this work.

## Unlimited growth?

There are hard constraints on some of our resources that research will not resolve. Globally, these include easily accessible oil, land area, freshwater supply, and the ability of the biosphere to absorb carbon emissions; locally these include freshwater, land around communities, and human capital.

The assumption of an unlimited supply of these resources cannot be justified, hence growth in demand will only be accommodated by solutions other than increasing resource use. These solutions go beyond just efficiency in resource use; they require a new operating paradigm of meeting growing needs within constrained resources.

Currently, we see this as impossible. However, if we dedicate even a small portion of our resources to exploring this possibility, we may contribute to the first solutions of this fundamental global problem. This represents an opportunity that we cannot afford to miss.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