People and energy: how do we use it?

Proceedings of a conference organised by the Royal Society of New Zealand in Christchurch
18 November 2004

Miscellaneous Series 66

Acknowledgments

The conference organisers thank the following sponsors:

Australian High Commission
Contact Energy Ltd
EECA (Energy Efficiency and Conservation Authority)
Solid Energy New Zealand Ltd

PO Box 598, Wellington, New Zealand

Miscellaneous series 66

ISBN 1-877264-17-2
ISSN 0111-3895

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Public talk

The emerging global and regional imperative—sustainable energy

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INTRODUCTION

In this paper I will:

- put energy use into its environmental context;
- look at the consequences of the energy solutions we now rely upon;
- highlight the benefits of shifting to sustainable energy solutions;
- and, finally, look at how a sustainable energy future is not only possible, but is practicable and, indeed, essential for humanity's future.

ENERGY AND OUR DEVELOPMENT

Energy is, indeed, an essential element of our lives. We need chemical energy from food to make our bodies work. Each day, a typical adult requires the equivalent of the energy in a 250 ml cup of petrol, or half a kilogram of wood, or the solar energy falling on a half square metre of ground, to function. In comparison with the enormous amounts of energy from other sources that people in developed countries consume, this is really very small. Nevertheless, even in the Stone Age, the humans with good access to food energy and fire, and who lived in conditions that required little energy to be used maintaining health, were advantaged. In our modern societies, energy underpins many important activities.

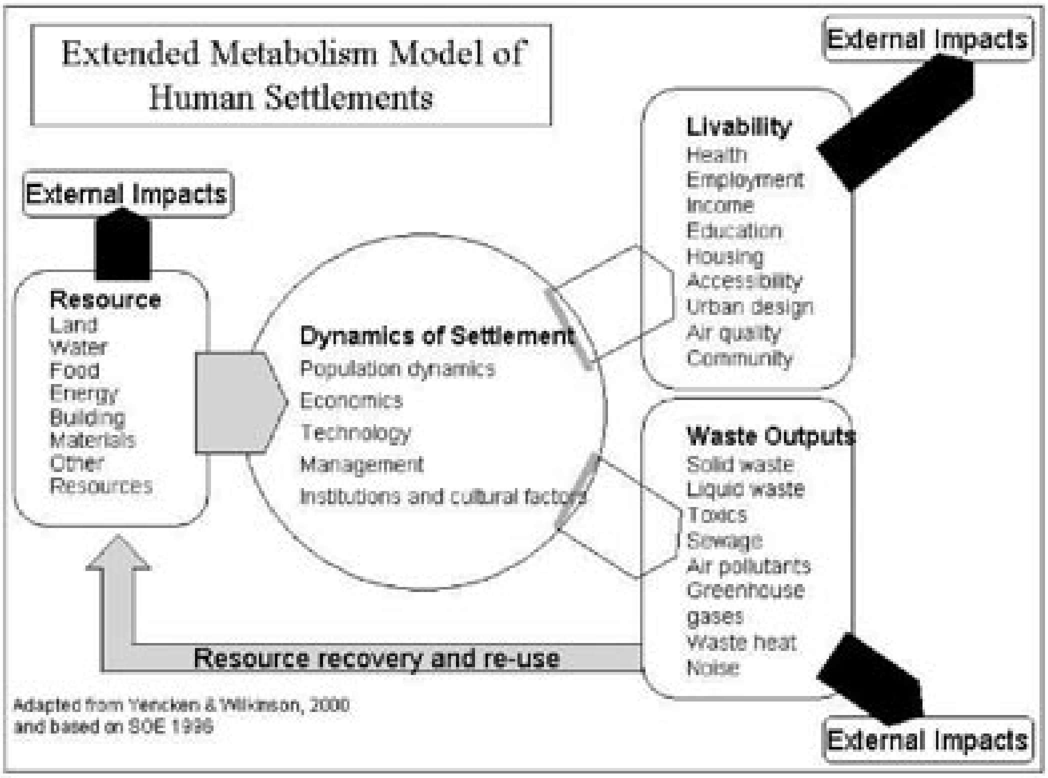

Fig. 1 Urban metabolism model highlights the important roles of energy (SoE 1996; Yencken & Williamson 2000, adapted by the author).

Figure 1 shows an *urban metabolism* model of a modern city, and energy can be seen as a critical factor, for example:

- Energy is used to produce food, fibre and materials used in the city.
- Energy is a direct input to run the infrastructure of a city.
- Energy plays a key role in delivering many of the services we value—mobility, comfortable buildings, communication and entertainment systems, food storage, and manufacture of materials and goods.
- Energy is a major contributor to the environmental and social problems of modern societies, both directly through burning of fossil fuels and harvesting of renewable fuels, and indirectly via the impacts of the technologies and systems that run on energy.

This model highlights the critical importance of energy to modern society. However, the model does not tell us that we need large quantities of energy, nor does it suggest that we need ever-increasing quantities of energy from fossil fuels. Those are assumptions made by politicians, business leaders, economists and many others in our society. This paper points out that, if we are smart, we can deliver the services we want and need with much less energy. And, as we reduce the amount of energy required for a given purpose, the economics and practicality of providing that energy from sustainably sourced renewable energy can look remarkably attractive.

WHAT IS SUSTAINABLE DEVELOPMENT?

Before we can consider the potential for sustainable energy, we need to know what sustainable development is, so that we can consider which forms of energy (and how they are developed) might be sustainable.

The concept of sustainable development became popular in the 1980s, with the release of the World Commission on Environment and Development's 1987 report *Our Common Future*—often called the Bruntland Commission report. This report defined sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

This concept has been developed and enhanced, with the important addition of an expectation that we should aim beyond not making things worse, but to leave a better world to our children.

One of the many more comprehensive definitions of sustainable development was published by the US National Commission on the Environment in 1993. It states:

> *A strategy for improving quality of life while preserving the environmental potential for the future, of living off interest rather than consuming natural capital.*
> *….. present generation must not narrow the choices of future generations but must strive to expand them by passing on an environment and an accumulation of resources that will allow its children to live at least as well, and preferably better than, people today. Sustainable development is premised on living within the Earth's means.*

In many ways, sustainable development reflects what every good parent might like to leave as a legacy for his or her children.

But broad statements like this require interpretation in particular circumstances. It can be useful to spell out the specific criteria that an action must satisfy if it is to be sustainable. Lumb et al. (2000) in Australia reviewed much of the work on sustainability and came up with the following principles, which have been interpreted by the author:

- *The precautionary principle*: this requires us to apply caution where there is risk of ecological impact. It can be interpreted as meaning that, because what we don't understand can hurt us and the environment, where there is doubt about impacts action should not occur. This shifts the responsibility onto the active agent to demonstrate that there is minimal risk of damage, rather than placing the responsibility on those opposing an action to prove beyond doubt that there is a risk.

- *Intergenerational and intragenerational equity*: this principle means that where an action diminishes the level of equity within the existing generation, or between the existing and future generations, it is not sustainable.
- *Maintenance of natural resources/capital*: this reflects the concept of living on "income" and not running down natural assets. Clearly it is not sustainable to run down environmental assets, because they will eventually be depleted.
- *Maintenance of biodiversity*: biodiverse systems are typically complex, with many interactive elements. Such systems are typically more resilient than monocultures and simple systems. So maintaining biodiversity enhances the capacity of the Earth's natural systems to function. Beyond this, there is also an element of respect for Nature, and recognition that humans do not yet understand the subtleties of many biological systems, so we should be reluctant to damage them. Further, there is an element of self-interest, in the recognition that future generations could potentially gain great benefits from biological systems. For example, we have already developed many medicinal and other products from natural systems.
- *Enhance economic and social wellbeing*: this principle reflects a desire to make the world a better place through sustainable action.

By considering an option against these principles, it is possible to assess its degree of sustainability and, more importantly, to understand in what ways it could be adapted or adjusted in order to make it more sustainable.

WHAT IS SUSTAINABLE ENERGY?

Let's now apply these sustainability principles to the major energy options available today:

- *Energy efficiency* – simply described as doing more with less energy, or making energy more productive. Since energy efficiency involves using less energy to deliver a given service, and hence a reduction in the environmental impact from energy use, and energy efficiency measures are often cost-effective, energy efficiency generally scores high on sustainability. There are sometimes situations where improving energy efficiency may involve trade-offs, such as use of different materials, or reduction in ventilation rates, although these can usually be resolved. And, where energy efficiency adds to the up-front cost of an action, intragenerational equity may be an issue. So, although energy efficiency usually scores high, its sustainability cannot be taken for granted.
- *Energy sufficiency*—being satisfied when we have "enough". This energy option is sometimes called energy conservation, and it includes an implication that the quality or quantity of service delivered will be limited. Critics often describe this as "freezing in the dark", and associate it with misery and loss of benefit. But the reality is that too much of anything can be not only unnecessary, but costly or damaging. Further, if equity objectives are to be met, it can be argued that distributing benefits more widely makes sense. This issue touches on an important aspect of modern society: traditionally, humans have struggled against the forces of nature just to survive. Today, we have enormous resources and great power and, in developed countries, great wealth. In many areas where external limits used to be applied, we humans must now make judgements about when to stop. This involves balancing benefits and costs in new ways—and we are not yet highly skilled in this. For example, we know that maintaining a house at temperatures above 16 C is important for human health, and we can do this in a well-designed energy-efficient house while using very little energy. But how warm is reasonable? Is it reasonable to expect to be able to wear tee shirts around the house in the middle of winter? And if you want to do this, should you expect to invest more in energy efficiency measures or other offsets so that you achieve this level of temperature without using more energy (and creating greater environmental impact) than other homes that are kept at more moderate temperatures?
- *Renewable energy*—forms of energy directly or indirectly supplied from solar energy over

a relatively short timeframe, or from a source that is so large that human activity cannot deplete it. The reality is that all forms of energy have environmental and social impacts. It seems that, if renewable energy is used within its resource limits and any associated environmental and/or social impacts are properly managed, it can be sustainable. The reality is that much of our present renewable energy use is not sustainable. For example, burning wood for home heating can cause air pollution (both indoors and outdoors) that can have serious health impacts. And harvesting wood can impact on forest biodiversity and deplete the resource. All these problems can be dealt with but in the past they have not been.

- *Fossil fuels*—forms of energy, such as coal, oil and natural gas, created over long periods from organic material. Since the timeframe for replacement of these resources is far longer than the period over which we are consuming them, we are running down a resource. However, where the use of fossil fuels is an investment in capacity to reduce future dependence on fossil fuels, a case can be made to go ahead. For example, using fossil fuels to make solar photovoltaic cells that produce much more energy than is used to make them may be justified for a period. But over time, it is reasonable to expect that some of the energy generated by the PV cells should be used in manufacture. So the reality is that this argument could only support limited use of fossil fuels. More importantly, using fossil fuels today fails the *precautionary principle* because there is a risk (and most would say a certainty) that burning them is driving climate change which has potentially very large impacts on humanity and all the Earth's systems. This failure could be overcome if the CO_2 released from fossil fuel combustion was captured and *permanently* stored. A technique called *geosequestration* has been proposed to solve this problem. However, this process will require at least a decade to develop and, on present indications, will be expensive and can only capture a proportion of the CO_2 emitted from fossil fuels (Saddler et al. 2004). While it may well be worth pursuing in case we fail to effectively address climate change, it is not a "first best" solution—that would be to avoid emitting CO_2 in the first place! In order to meet sustainability criteria with fossil fuels, it would also be essential that other environmental and social impacts associated with their use are properly managed. These include air pollution, alienation of land, social impacts in oil-producing regions, and so on.
- *Nuclear energy*—energy produced by breaking apart or fusing together atoms (although practical fusion power generators have not yet been developed). Proponents of nuclear energy see rising concerns about climate change as an opportunity to reinvigorate their industry, as it generates no greenhouse gas during operation. However, sustainability involves consideration of multiple dimensions. Nuclear energy leaves dangerous wastes for future generations, so it raises questions about intergenerational equity. The potential consequences of a single incident, such as a mistake by operators or a terrorist attack, are large, and there is potential for waste materials to be used for "dirty bombs" or even nuclear devices which could undermine global peace and stability, so the *precautionary principle* is not met. And electricity is only 25% of New Zealand's energy requirements (NZ Government 2004), and 16% of world energy requirements (NZ Government 2004a). So to use it to provide much of the world's need for heat and movement may potentially be both inefficient and expensive.

In summary, no form of delivery of energy services is guaranteed to be sustainable under all conditions. However, energy efficiency improvement, energy sufficiency and, under appropriate conditions, renewable energy, have potential to rate well. Under certain conditions, fossil fuels and even nuclear energy may be considered to be less unsustainable than present practices, and there may be potential for geosequestration to make some fossil fuel use potentially sustainable. But, given the well defined potential of energy efficiency and renewables to underpin a sustainable energy future, focusing on the other options may simply divert scarce resources and waste time.

WHY IS SUSTAINABLE ENERGY IMPORTANT?

If provision of energy in a sustainable manner was a minor issue, we need not worry about it. So let's look at why it is important.

Energy and sustainable development

Sustainable energy is a key element of sustainable development. Figure 1 showed the critical role energy plays in the functioning of modern society. We need access to affordable, sustainably-sourced energy for all natural and human systems to operate. It's as simple as that. But, there is room for debate about how much energy we need, because energy is not an end in itself, but is an input into the delivery of services, such as comfortable homes and access to facilities, which are the things we really want and need. That will be discussed later.

Energy and the local environment

Use of energy impacts on the local environment, both indoor and outdoor, so sustainable energy use must involve avoiding such impacts. A good example of the kind of local impact that can occur is air pollution. In cities such as Christchurch, use of large numbers of wood heaters, combined with use of fossil fuel powered vehicles and wood and fossil fuel use in business, can cause serious health and amenity problems (Scott & Gunatilaka 2004). This can include emissions of particulates, carbon monoxide, and oxides of nitrogen and sulphur. Energy production and delivery also impacts on the local environments where such activities occur.

Energy and global issues

Energy use at the scale we now operate is impacting on the global environment. It is a major element of human impact on the global environment. Analysis of the *ecological footprint* of individual countries as well as global population confirms that, on average, energy is responsible for 49% of a human's ecological footprint (McDonald & Patterson 2003). The ecological footprint is a method of quantifying a range of environmental impacts in terms of one indicator, the area of land that can provide the services required to support a person's life. Typically, the result is reported in hectares of land per person, and is categorised as agricultural land, forest land, degraded land and energy land. The area of energy land is determined by calculating the area of trees that could sustainably supply the energy used per person in a given country or region. In New Zealand, the energy component of the average ecological footprint is only 17% of the total footprint, because of New Zealand's relatively high usage of renewable energy and the rapid growth rate of trees in its conditions. Nevertheless, this approach highlights the significance of energy issues around the globe.

Another major impact associated with present energy use is climate change. Over 60% of the warming effect can be attributed to emissions from the combustion of fossil fuels (www.manicore.com quoting IPCC). Over the past century, the concentration of carbon dioxide (the main greenhouse gas) has risen dramatically, from under 300 parts per million (ppm) to 379 ppm, as shown in Figure 2. Analysis of the carbon isotopes in the gases confirms that much of the increase is due to combustion of fossil fuels. This can be explained fairly simply. Over the past century, humans have released 3–5% of all the carbon fixed in fossil fuels over millions of years. And, over the next 25 years, another 3–5% will be released if we continue on our present path. The Earth's carbon cycle simply cannot absorb such large quantities of additional gas. Humans are effectively conducting an experiment to see how the atmosphere will cope with a large injection of carbon dioxide over a short period: this does not meet our sustainability criteria. If we were following the precautionary principle, we would have significantly curtailed out greenhouse gas emissions some years ago, while continuing research to understand the implications better.

There is strong evidence to suggest that the Earth has warmed quite rapidly over the past 30 years in response to a number of factors including the increase in concentration of greenhouse gases in the atmosphere. This reinforces the urgency of response to climate change.

New Zealand's contributors to global greenhouse gas emissions in 1990 and 2002 are shown in Figure 4. This shows that, unlike most developed countries, energy-related emissions are not New Zealand's dominant contributor to gross greenhouse gas emissions. However, once the impact of carbon absorption by vegetation is taken into account, energy-related emissions were 63% of net emissions in 2002, up from 60% in 1990 (MoE 2004). Since New Zealand's energy-related greenhouse gas emissions are expected to increase under Reference Scenario conditions (MED 2003), and the long-term global objective is a large reduction in net greenhouse gas emissions, energy is an important focus for greenhouse policy.

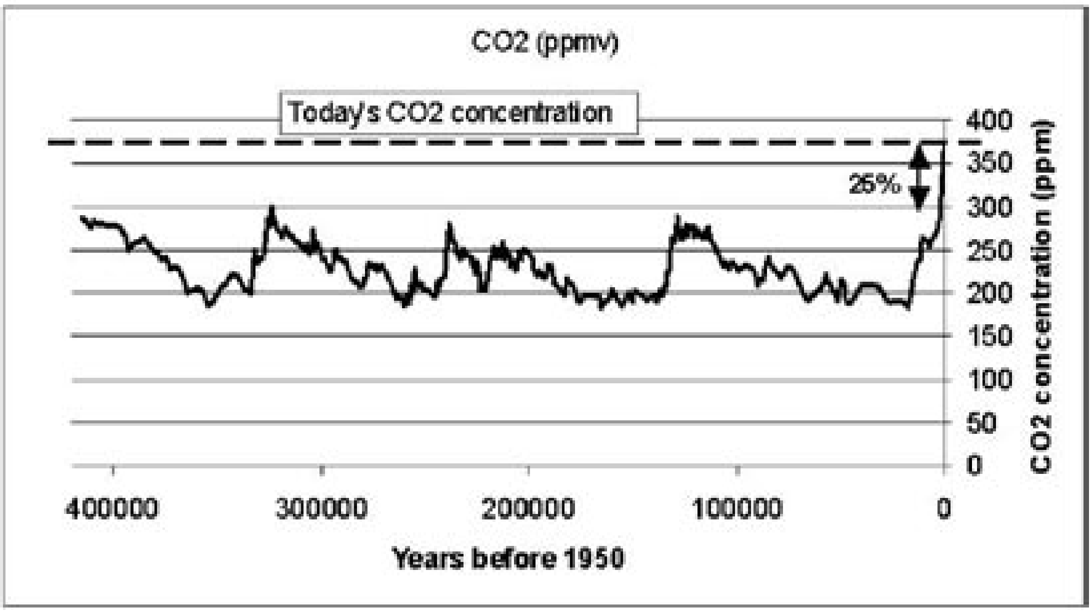

Fig. 2 Carbon dioxide concentrations in the Earth's atmosphere over the past 400,000 years. (Vostok ice core data to 1950, then IPCC data).

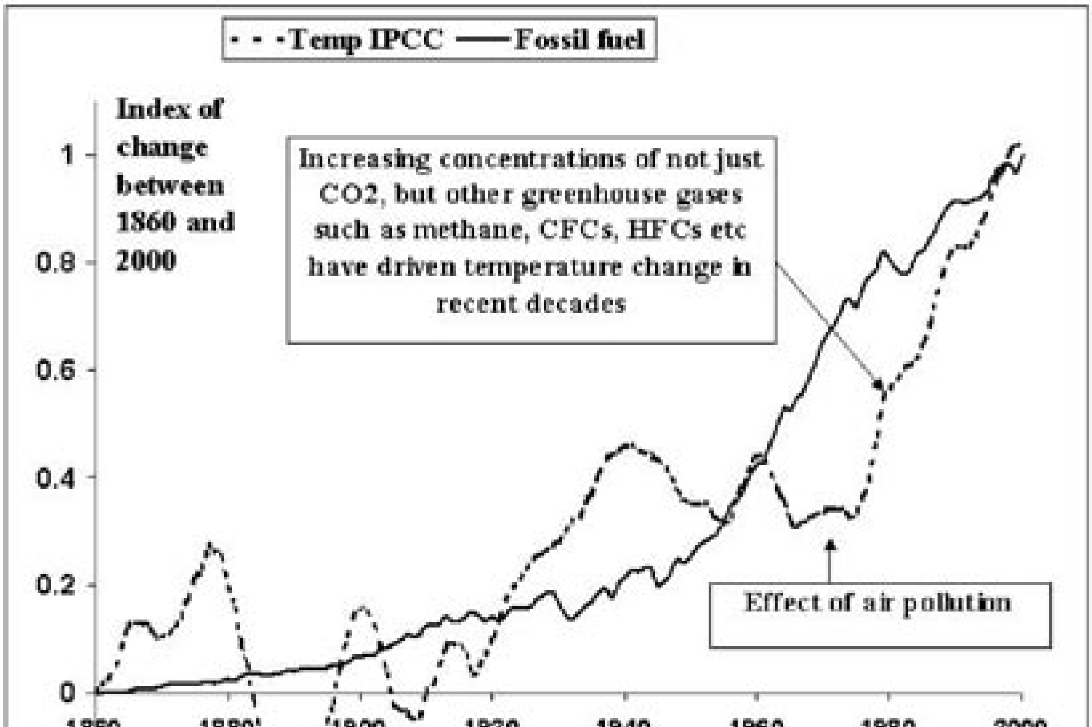

Fig. 3 Correlation of global temperature and fossil fuel use (BP Review for fossil fuel data, IPCC for temperature data) using an index of 1 to reflect the change in each factor between 1860 and 2000.

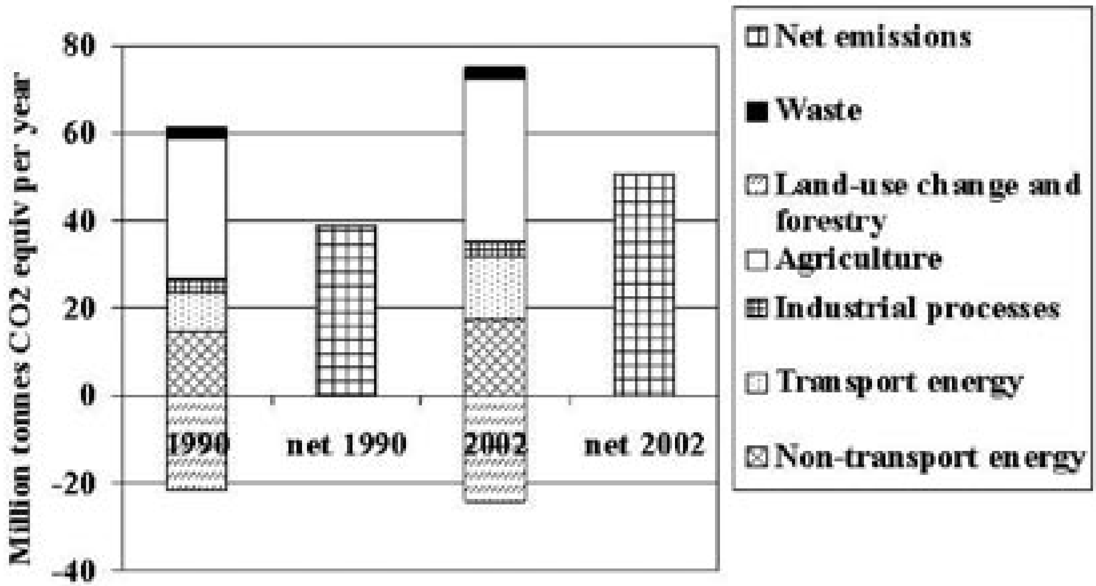

Fig. 4 New Zealand greenhouse gas emissions, 1990 and 2002. Increasing storage in trees and response strategies are expected to return net emissions to 1990 levels by 2008–12 in accordance with Kyoto Protocol commitments, but energy-related emissions are expected to continue growing in the longer term. (MoE 2004, transport emissions estimated from NZ Government 2004c).

Energy and equity

At a global level, energy is a key factor in equity. Access to modern energy services at affordable costs is just a dream for almost a third of the world's population.

Within a country such as New Zealand, equity-related energy issues include the following:

- Tenants and low income households often live in thermally inefficient housing, which increases living costs, adversely affects health, and creates discomfort.
- The poor, young, old and unlicensed people may not have access to a car, or be able to afford to run it, so a car-based society creates inequity for these groups. According to the New Zealand Government (2004b), 30% of New Zealanders do not have access to a car. Even for those who have a car, many spend time as unpaid chauffeurs, driving those who cannot drive to where they need or want to go.
- There is inequity of access to information and resources needed to implement energy and cost saving measures, as well as renewable energy solutions

Energy and security

Energy security issues occur at a number of levels.

At a local and regional level, ensuring that energy supply capacity and demand are balanced is important for the economy and quality of life. This is a particular issue for electricity, where supply must meet demand from minute to minute. Energy efficiency and management of energy demand can play a valuable role in reducing peak energy demand, or shifting it to times when more energy is available or it is cheaper to supply. For example, Isaacs (2004) has noted that replacing conventional lights with compact fluorescent lamps could cut New Zealand's winter peak electricity demand significantly.

Where we rely on centralised energy systems for energy supply, a failure at any point in the supply chain can have severe impacts on the economy and the community. This was seen some years ago in the central district of Auckland, when power supply cables failed.

At the national level, dependence on imported energy has significant implications. First, it adds to Balance of Payments problems. Second, where there are few suppliers, and/or the availability of an energy source may be limited, there are risks of supply interruptions and variations in price. New Zealand imports most of its oil, and demand is increasing (MED 2003), while an increasing number of experts believe world oil production will soon peak. Recent high oil prices may have been an important warning for countries in New Zealand's position.

Access to energy services is an important factor underpinning a country's or region's economic and social development. In the past, this has meant increasing supplies of energy. But today, it can mean reducing the need for energy by becoming more energy-efficient.

TRENDS IN ENERGY USE

Globally, the trend in energy consumption, including fossil fuels, is upwards (BP 2002), although growth rates have slowed from those of previous decades. In New Zealand, the trend is also upwards, as shown in Figure 5.

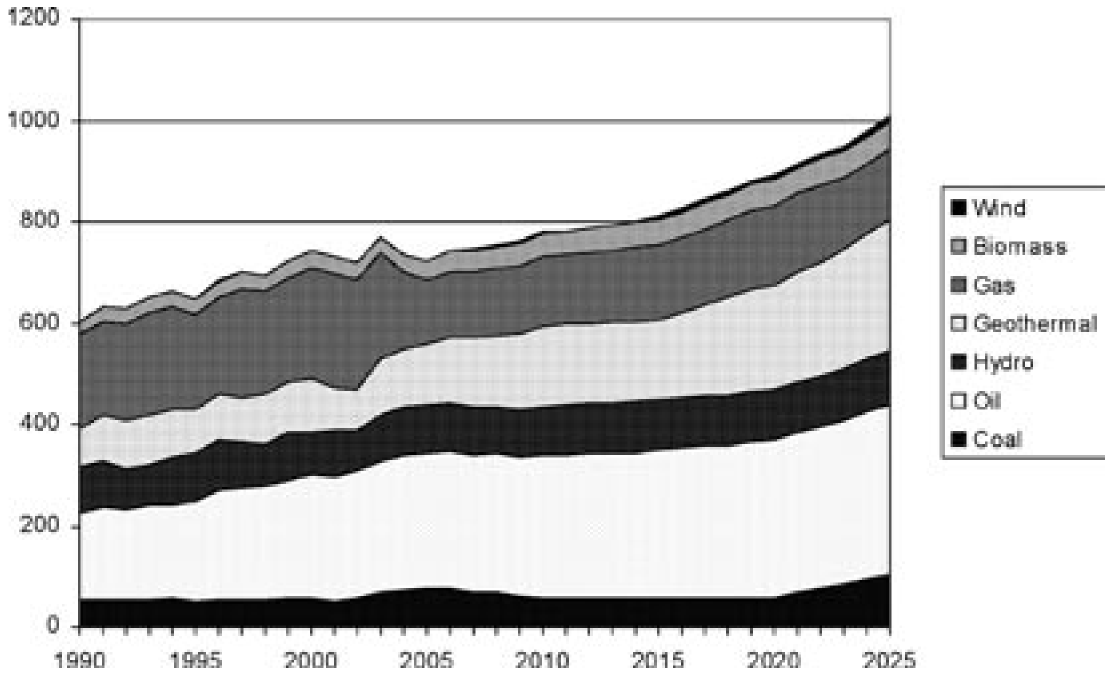

Fig. 5 Reference Scenario primary energy trend, New Zealand. Energy-related CO_2 emissions are expected to increase at 0.8% pa to 2025. (MED 2003).

Many factors are driving this growth, including economic development and improvements in quality of life. However, particularly in more affluent countries, our enormous wealth is leading to choices that reflect extravagance rather than need. In many cases, the full costs of these choices are not paid by those who make them. For example, the full environmental costs of energy and resources are generally not included in their prices, and the cost of satisfying high peak demand in a large house is not reflected in energy prices. The owner of a large 4-wheel-drive that causes greater injury to the occupants of another car does not see that cost. And so on. This is a real challenge for modern societies. Is it feasible to ensure that people pay the full cost of their actions? Can information programmes highlight the hidden consequences of decisions such as the time and cost of cleaning, maintaining and running a very large home? Do we need to regulate excesses? Do we need to focus on developing human values that consider community and global outcomes over personal short-term benefits?

PRIORITY ENERGY ISSUES FOR NEW ZEALAND

The following summarises the major issues that emerge from a review of recent New Zealand energy literature:

- **Oil:**
  —85% used for transport and demand is growing;
  —Most is imported—Balance of Payments, security issues.
- Coal:
  —Large quantities available, but major climate change impacts, especially if used for inefficient centralised electricity generation.
- Gas:
  —Big gas fields running down, future supply from smaller more expensive fields, or possibly imports.
- Renewables:
  —Well-established, large potential at reasonable cost, but little contribution to transport fuel to date.
- Energy efficiency (doing more with less energy);
  —Patchy performance to date, new strategy (EECA, 2001) only aims to slow growth in energy use. Enormous potential.

In addition, there are significant concerns about the capacity of the electricity supply system to cope with demand, especially in years of low rainfall and in regions where population growth is rapid.

OPPORTUNITIES FOR SUSTAINABLE ENERGY SOLUTIONS IN NEW ZEALAND

Renewable energy

Renewable energy already provides close to a third of New Zealand's primary energy, which is high in comparison with most developed countries. These energy sources include hydroelectricity, electricity from geothermal and wind energy, and heat from biomass (wood and wastes) and geothermal sources. Solar energy is, of course, used to grow agricultural crops and contributes to space heating of many homes, although little of this is documented. New Zealand also has well-documented renewable energy resources, and hydro, geothermal and wind energy are expected to make major contributions to expansion of electricity supply capacity in coming years (MED 2003). It also seems to have the academic and technical capacity to pursue these options.

A key issue for New Zealand renewable energy is to increase its contribution to transport energy supply. As noted above, imported oil is a major emerging issue for New Zealand, so that contributions from renewable energy sources such as biodiesel, alcohol, possibly biogas, electricity (for public transport and local travel) and, in the longer term, hydrogen will be potentially very important.

Because of the advanced stage of development and awareness of renewable energy in New Zealand, this paper will focus more on energy efficiency issues, which seem less developed.

Energy efficiency

Energy efficiency improvement is far more important than many people, including energy suppliers, seem to realise.

In the New Zealand context, saving energy is important in a number of ways, including:

- managing peak electricity demand problems;
- helping economic development;
- reducing air pollution from home heating while containing household energy costs;
- achieving greenhouse targets, as energy-related emissions are a significant and growing part of New Zealand's emissions.

More generally:

- It is often the most effective way of cutting costs.
- It is usually the most sustainable option to cut environmental impacts.
- It often offers a range of benefits beyond energy saving that may include avoiding capital investment in energy supply infrastructure, making seemingly impossible activities possible, improving productivity or quality.

Energy efficiency can transform our understanding of what is possible. For example, mobile phones and laptop computers rely on extremely high efficiency to be practicable. A solar car uses only about 1.6 kilowatts of energy to travel at 100 kilometres per hour, so it becomes practicable to power it using an array of solar cells that fits onto the car itself. A conventional car would require around 150 square metres of solar cells—not very practicable!

In this short paper, it is only possible to offer some examples of the kinds of options we have to apply energy efficiency to make our lives more sustainable and enjoyable, while improving the economy:

In transport, energy efficiency opportunities include:

- reducing the need to travel by re-organising the way our cities are structured, so that access to services is improved;
- replacing travel with other emerging options such as telecommunications (mobile phones, video-conferencing, email, etc);
- utilising more energy-efficient and appropriate forms of transport, such as public transport, bicycles, walking, electric buggies and scooters, and so on;
- managing vehicle loading and usage more efficiently, using intelligent information systems, logistics management and other strategies;
- utilising more fuel-efficient vehicles. Already we can buy high efficiency diesel and hybrid cars (hybrid cars have a petrol engine, an electric motor/generator and battery storage, so that energy normally wasted during braking can be stored and used to accelerate the car, and smart systems can optimise the operation of both forms of propulsion). These cars deliver fuel consumption of 4-6 litres/100 kilometres, cutting fuel use by 30–60%. But future generations of cars will use 1–3 litres/100 kilometres, by incorporating advanced technologies such as fuel cells which will be compatible with emerging energy sources such as hydrogen.

In our homes, we are also seeing dramatic improvements in energy efficiency, including the following:

- Improvements in efficiency of refrigerators and freezers. In Australia, appliance energy labelling and minimum energy performance standards have led to a 70% improvement in energy efficiency since the mid 1980s—and the net benefits now add to over $100 million each year. New Zealand has recently adopted this approach, and can be expected to benefit significantly, as refrigeration comprises around 10% of household electricity usage (Isaacs 2004).
- While lighting energy use has increased in recent years with the widespread adoption of inefficient "low voltage" halogen lamps, emerging alternatives including micro-fluorescent lamps and LEDs (Light Emitting Diodes as used for bicycle lamps) now offer savings of up to 80%.
- Improvements in insulation, draught-proofing, advanced glazing systems and building design, along with heating appliance efficiency improvements, mean that new homes can be far more comfortable while using up to 90% less heating and cooling energy than older homes.
- While recent trends towards large plasma screen televisions have been increasing energy use by home entertainment equipment, this trend is about to be reversed. Liquid Crystal Displays (LCD) of sizes similar to plasma screens are now becoming available. They use less than a third as much energy as plasma screens and, indeed, may use less than older

conventional TVs they replace. In the future, Organic Light Emitting Diode televisions are expected to appear, that will use half as much energy as LCD screens. Then, a large screen TV could use less energy than a small 34 cm portable TV (Sustainable Solutions 2003). And with smart controls to vary the brightness, and to shut equipment down when not required, even larger savings will be achievable.

In this paper, there is insufficient space to consider business energy saving opportunities in much detail. In the commercial services sector, though, energy use is dominated by the requirements of keeping people comfortable and providing lighting: many studies and practical projects have demonstrated that large savings of 50–90% are practicable in these areas. In industry, most energy is used by energy-intensive industries, most of which produce materials such as metals, glass, cement, bricks and paper. In these areas, a mix of strategies that includes reducing demand for virgin materials (through re-use, recycling and reducing material content of products), switching to lower environmental impact materials, improving the efficiency of industrial processes, and utilising renewable energy sources can also deliver large savings in fossil fuel and total energy consumption.

CONCLUSION

Sustainable energy *is* an emerging global and regional imperative. If we don't get it right, we face serious economic, environmental and social problems. But the practical options are there. And, in New Zealand, Government strategies are emerging that have the potential to respond to the challenges and capture the opportunities. We all have to play our part but, if we do, we can enhance our lives and those of our children instead of making them miserable. That's what sustainable energy is all about.

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Session 1

Human needs

Supply requires demand—where does all of New Zealand's energy go?

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ABSTRACT

The Micawber Principle (expenditure should not be greater than income) applies equally to energy (ever-increasing demand must be matched by ever-increasing supply) as it does to finances. Today's research and planning is largely focused on new sources of energy supply, and their conversion and transmission to the end user. The focus is on ever-increasing supply to meet an apparently ever-increasing demand, rather than understanding the underlying causes of demand. The paper examines New Zealand society's energy demand, and through historical review looks at the widely diverse drivers for increasing demand. The latest research results from the Household Energy End-Use Project (HEEP) will be used to illustrate opportunities for improved energy supply system planning through improved understanding of energy demand.

INTRODUCTION

> *Another piece of advice, Copperfield," said Mr. Micawber, "you know.*
> *Annual income twenty pounds, annual expenditure nineteen nineteen six, result happiness.*
> *Annual income twenty pounds, annual expenditure twenty pounds ought, and six, result misery.*
> *The blossom is blighted, the leaf is withered, the God of the Day goes down upon the dreary scene, and—and in short you are forever floored.*
> *As I am!* (Dickens 1850)

Where would Mr Micawber be today? After visiting his local Citizen's Advice Bureau, he would be guided to a Budget Advice Service, where the first question would be to ask him to set out details of his income and expenditure.[1]

The problems that result from the need for ever-increasing demand (expenditure) to be matched by ever-increasing supply (income) can be seen in the energy sector as well as a household. For example, the past year has seen activity due to:

- a short-term crisis, as rain did not refill the hydro-lakes;
- uncertainty that the Maui natural gas field may be reaching the end of its theoretical economic life;
- increased international oil prices as demand growth does not appear to be matched by comparable short or long-term growth in oil supplies.

Now is an appropriate time to review the supply and demand of energy in New Zealand, starting with a budget review—what are the details of energy supply and demand?[2]

[1]www.cab.org.nz is an excellent first step.

[2]Note: In this paper percentages in tables or on charts may not add to 100 due to rounding.

NEW ZEALAND ENERGY SUPPLY

Twice a year, the Ministry of Economic Development (MED) publishes the Energy Data File which provides official statistics on energy supply and consumption in New Zealand (MED 2004a). It is based on analysis of energy imports and production, plus mandatory reporting by energy supply companies of deliveries by sector. The following analysis is based on this publication.

Figure 1 illustrates the proportions of New Zealand's main fuel sources—including the use of oil and natural gas for "non-energy" purposes (e.g., fertiliser, roading, etc). "Other renewables" includes electricity generation from wind, biogas, industrial waste and wood.

Figure 1 shows that New Zealand's single most important fuel source is the fossil fuel, oil. Over the past 30 years oil has decreased from just under half (48% in 1975) of the total primary energy supply, to over one-quarter (around 28% in the 1980s), but since then has steadily increased to the current 38% (2003 provisional data). In the same time, total annual primary oil use has increased from 185 PJ to 278 PJ—an increase of 50%.

NEW ZEALAND ENERGY DEMAND

But where does all this fuel go? Figure 2 re-evaluates the national energy data from a consumer demand perspective. Not surprisingly, the largest fuel supply (oil) feeds into the largest consumer demand (domestic transport). The importance of oil is at variance with the reports in our general and business news media, which are largely focused on electricity.

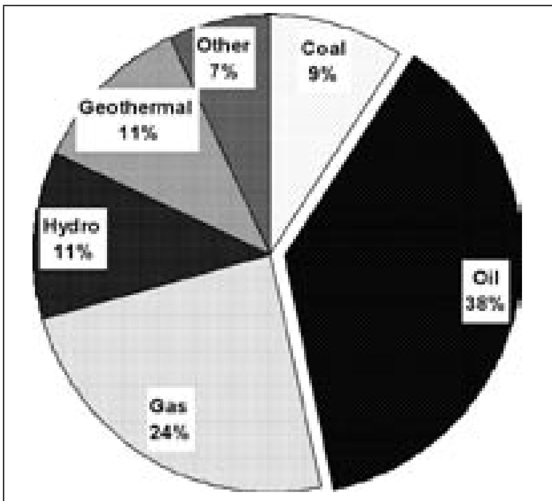

Fig. 1 NZ 2003 primary energy by fuel.

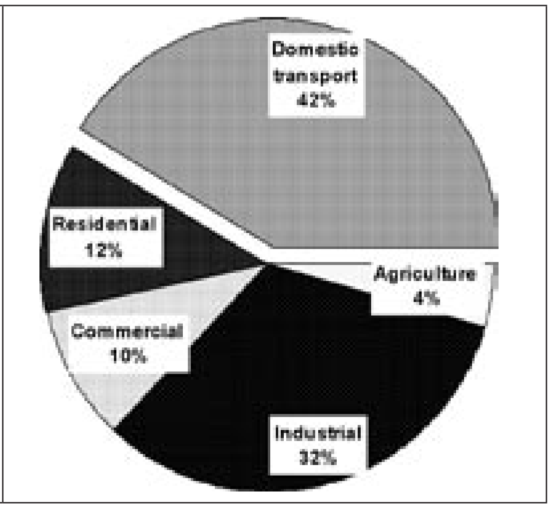

Fig. 2 NZ 2003 consumer energy by sector.

Figure 3 compares the fuel types used in the different sectors of the New Zealand economy, with the total demand by sector provided at the top of the graph.

Agriculture and domestic transport are the most oil-intensive sectors, but it is worth noting that all sectors of the economy make use of the "transport" sector—in the main, apart from a relatively small fuel use for motor sports, transport is a service sector. It should also be noted that the "commercial" sector includes public lighting, rail and urban traction.

Currently the residential sector consumes about one-third (34%) of consumer electricity, but just under 30 years ago this was close to one-half (48% in 1976). Thus, although electricity is so critical to the residential sector, other sectors now play a more significant demand role.

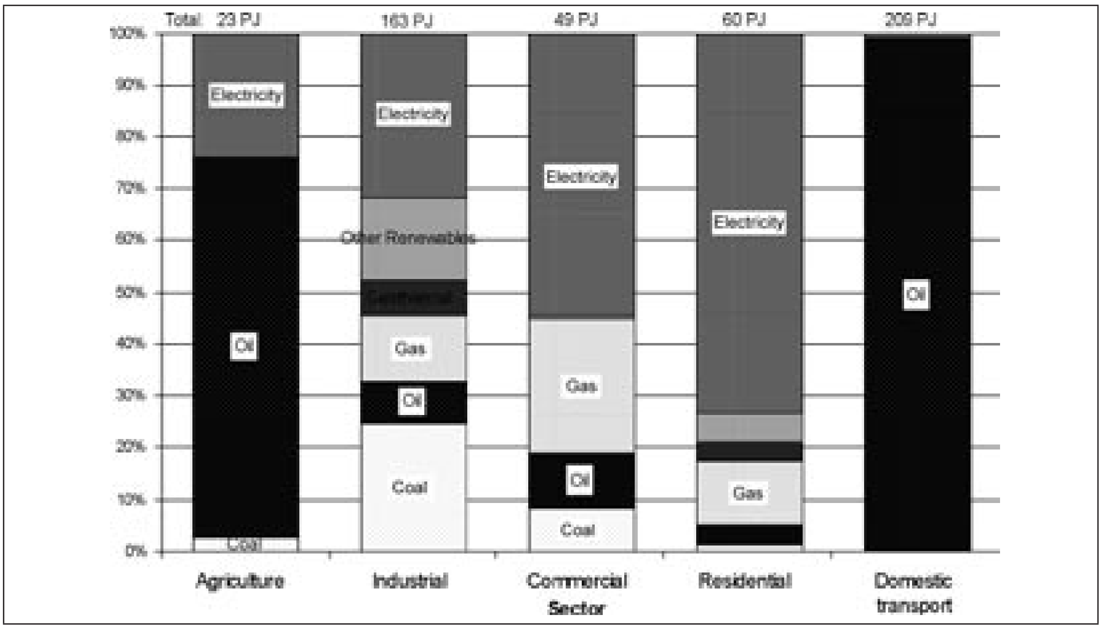

Fig. 3 NZ consumer energy demand (2003) by sector and fuel.

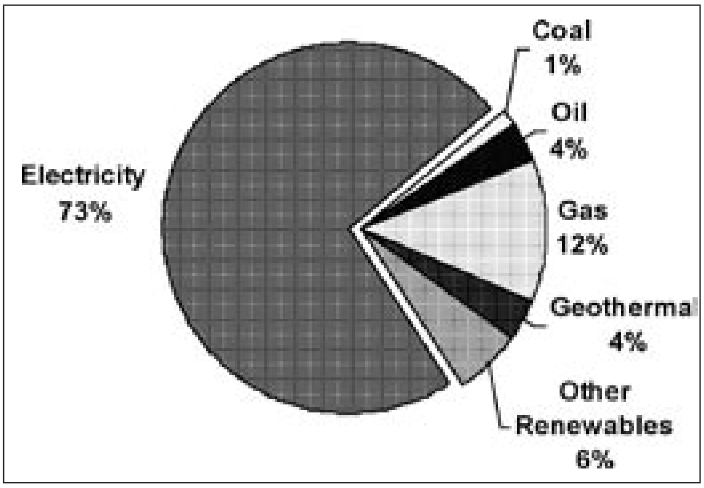

Fig. 4 Residential sector energy use by fuel 2003.

Examining only residential sector fuel, Figure 4 shows that electricity is just less than three-quarters (73%) of the energy used in the residential sector, with natural gas following second at 12%.

"Other renewables" at 6% is followed in order of importance by oil and geothermal at 4% and coal at 1%.

Have there been any changes in residential energy demand?

> *The relative energy intensity of an average household today is not much different from what it was 30 years ago—and yet we are using far more convenience devices and appliances today.* (Doug Heffernan, CEO Mighty River Power—quoted in Schäffler 2004)

There are two parts of this statement to be considered—whether energy intensity has changed, and the importance of the convenience devices and appliances.

The first part of this statement does not seem unreasonable. Based on the number of *occupied permanent private dwellings* recorded in quinquennial censuses and the Energy Data File (MED 2004a), residential energy use per household has increased by only 6% over the period 1971 to 2001. In the same time, the population has increased by 34% and the number of households by 61%, so there are less people per house. The result—total residential sector energy use has increased by 70%, and energy use per person has increased by 27%.

The most recent decade shows a slightly different picture. Figure 5 (data from MED 2004a and Statistics NZ 2004) plots total residential energy consumption (PJ), consumption per household (GJ/household)[3] and per person (GJ/person) from 1990 to 2004. Figure 5 shows the following increases over the period 1993 to 2004:

- total residential sector energy use by 8%;
- the number of households by 17%;
- the number of people by 15%.

The consequence of these changes is that the average energy use per household has fallen by 8% and the residential energy use per person by 6%.

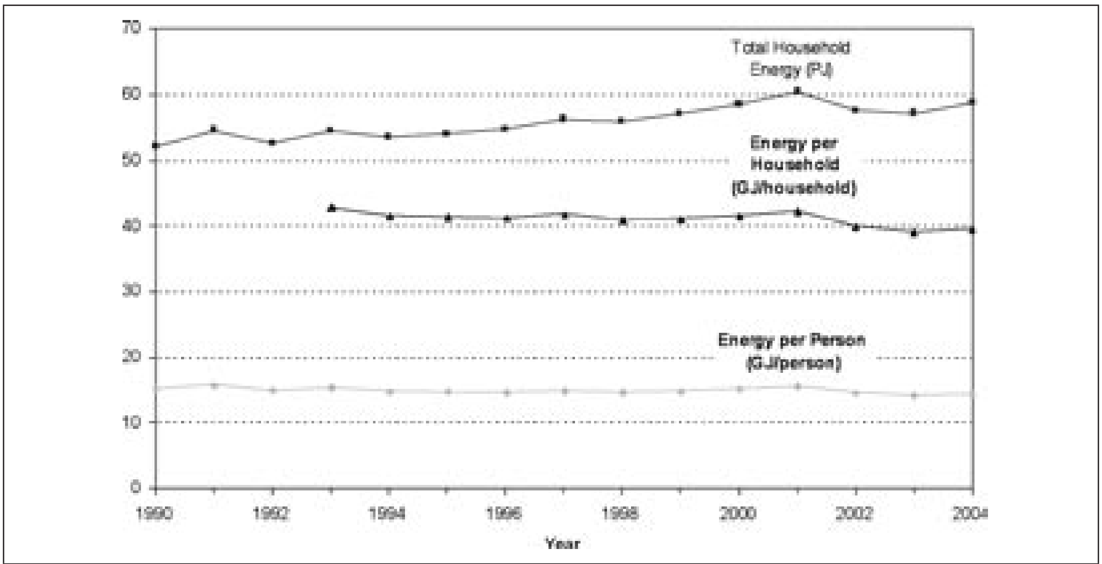

Fig. 5 Residential energy consumption 1990–2004.

The patterns shown in Figure 5 are related to more than just energy use. For example, New Zealand households show a long-term trend of falling occupancy rates—reducing from 2.8 people per household in 1991 to 2.7 people in 2001 (Statistics NZ 2002). Structural changes in households (e.g., number of people per household) need to be considered as much as structural change in technology.

But what about the last part of the statement—*yet we are using far more convenience devices and appliances today.* Where does energy use go in New Zealand homes? Are convenience devices and appliances so important in their energy use, or do other uses drive the residential sector energy use? This information is not available from the supply data used to prepare the Energy Data File, so it is necessary to find other sources.

Investing in energy demand knowledge?

Before committing any funds, the wise investor looks carefully at all possible investments—noting the different risks and opportunities. The first step is careful research to obtain the necessary data for analysis. Data are not collected without funding support, so who is funding the search for such data in New Zealand?

[3]Note: The "Permanent dwelling" series previously used is no longer available, so the results presented here are based on "estimated households" and thus differ from the HEEP Year 6 Report.

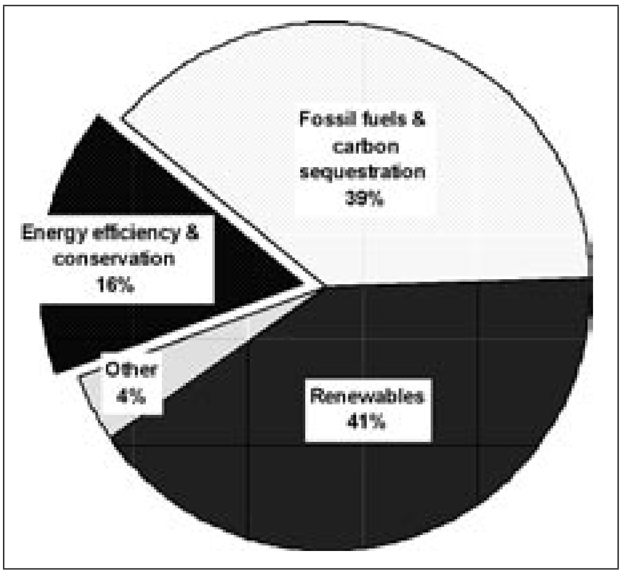

Fig. 6 FRST energy research budget 2003/4.

Figure 6 summarises the Foundation for Research, Science and Technology 2003/04 budget for energy research (MED 2004b). The total budget was $12.2 million, of which $2 million was invested in "energy efficiency and conservation". No comparable data are available for private sector investment.

Figure 6 shows that the majority of Government "energy" research is concerned with supply. Apart from the HEEP, it is clear that there is only limited new work being carried out into understanding energy end-uses in other sectors of the economy. It is thus necessary to first look to historical data.

WHAT USES HOUSEHOLD ENERGY?

For the past 30 years, almost all knowledge of household energy use has been based on the 1971/72 Household Electricity Study, conducted by the then New Zealand Electricity Department and the Department of Statistics (Statistics NZ 1973). As the title would suggest, it was concerned solely with electricity use—the use of other fuels (e.g., for water heating, cooking or heating) was recorded, but no estimate made of that fuel use.

Figure 7 illustrates electricity breakdown by end-use from the 1971/72 study—the three largest uses of electricity being water heating (44%), other appliances including lighting (28%) and home heating (15%) (Statistics NZ 1976). The data used in Figure 7 are subject to a number of caveats in the original report:

- The winter of 1971 was exceptionally mild, suggesting less heating was used than for a more normal (i.e. colder) winter.
- The majority of houses used "electricity and other fuels" as their main means of home heating (74% of the insulated houses, 68% of the uninsulated houses) but no estimate was made of the non-electricity heating fuel use.
- 19% of the houses used electricity and some other fuel for the provision of hot water, but again no estimate was made of the non-electricity fuel use.
- The sample included 315 "insulated" (19%) and 1336 "un-insulated" (81%) houses, but the presence of insulation was associated more with higher income groups and a more widespread use of electric heaters.
- The insulated houses in the matched sample were not only warmer, but also consumed 40% more heating electricity (1,632 kWh vs 1,158 kWh).

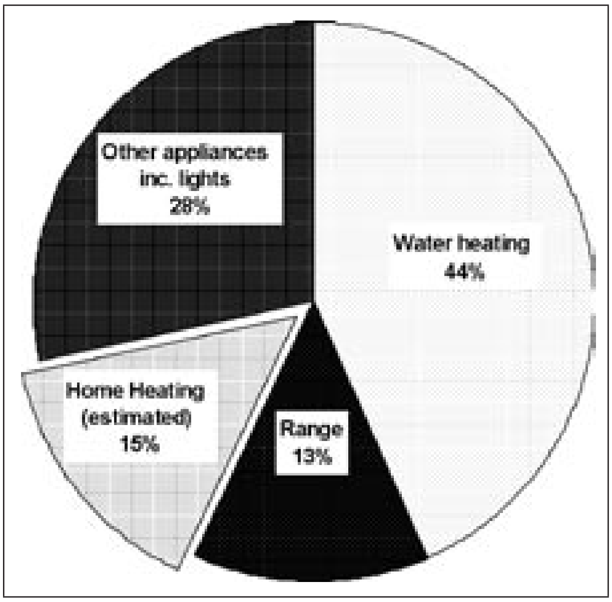

Fig. 7 1971/72 NZ electricity end-uses.

By the end of the 1970s, natural gas was becoming available in major locations throughout the North Island, an oil crisis had shifted residential interest away from oil as a form of space heating and improved solid fuel burners were replacing the open fire.

There were also changes in both technical and social aspects of the way houses were built and used, with largely unknown energy consequences. There have, for instance, been significant changes in:

- materials (e.g., large sheet particleboard for flooring has replaced strip flooring);
- the NZ Building Code (e.g., thermal insulation has been required since 1978);
- appliances (e.g. microwave ovens have been widely available from the late 1970s);
- electronic controls (e.g., remote controls require "standby" electricity);
- work practices (e.g., retailing is now a seven-day-a-week operation);
- house layout (e.g., greater use of open plan living spaces);
- home energy consumption such as home offices (e.g., home computers);
- household characteristics including household ethnicity, size and age composition.

Although the need to understand these changes has been publicly discussed since the early 1980s (e.g., N.Z. Parliament 1984), it was not until late 1995 that the Building Research Association of New Zealand, Inc (BRANZ) started the Household Energy End-use Project (HEEP) with a pilot study of 10 houses in Wanganui (Stoecklein et al. 1997).

HEEP is a multi-year, multi-discipline, New Zealand study that is monitoring all fuel types (electricity, natural gas, LPG, solid fuel, oil and solar used for water heating) and the services they provide (space temperature, hot water, cooking, lighting, appliances, etc). The monitoring of 400 randomly selected houses will be finished in early 2005, with a national residential sector energy model to be completed in 2007. Preliminary results from the HEEP work have been published annually since 1997.[4] It should be noted that the results reported in this paper are subject to change as data processing proceeds.

Figure 8 provides preliminary HEEP estimates of electricity end-uses for Auckland houses.

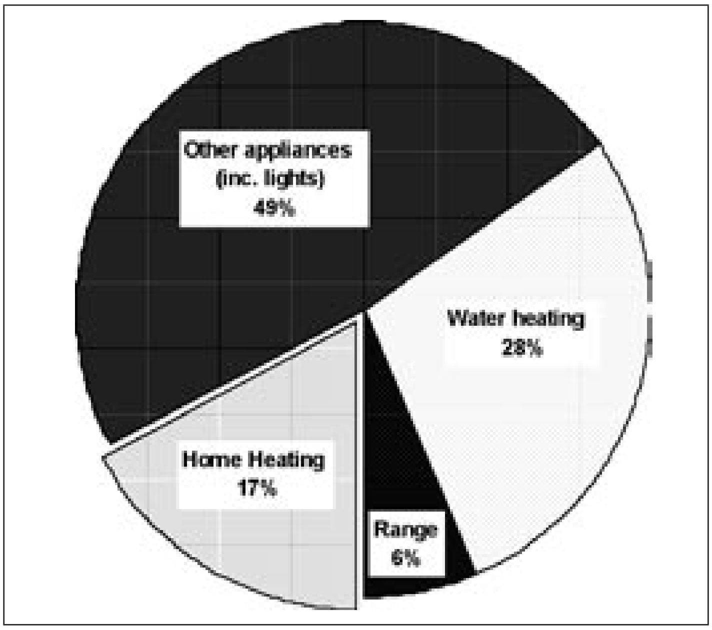

Fig. 8 HEEP estimate of Auckland electricity end-uses.

While the household electricity use is similar (8400 kWh/yr in 1971/72 New Zealand average compared with 7900 kWh/yr for the Auckland HEEP houses), the main three end-uses of electricity

[4]For latest results, see the BRANZ website: www.branz.co.nz/main.php?page=HEEP

have shifted considerably from the pattern found in 1971/72 (see Figure 7):

- Appliances (including lights) have increased from 28% to 49%.
- Home heating remains about the same at 15% in 1971/72 and 17% in HEEP.
- Water heating has reduced from 44% to 28% of electricity use.
- Range (oven and hobs) has reduced from 13% to 7% of electricity use.

A closer examination of the HEEP data finds that lighting (about 15%) and refrigeration (about 10%) each account for a sizable portion of the electricity use. The importance of these uses has not previously been recognised, possibly due to a lack of end-use data or perhaps because each is only a small power load. However, a small load turned on and used for a long time (e.g., a heated towel rail operating all day, all year) uses as much energy as a large load turned on for a comparatively short time (e.g., electric clothes dryer used 90 minutes daily).

Understanding electricity use does not provide an adequate understanding of household energy use. Although it is possible to use electricity for all household uses, very few houses use only electricity. In particular, most households use more than one fuel for space heating.

The results of the most recent HEEP energy analysis are reported in Figures 9 and 10. They provide preliminary energy estimates based on the 300 randomly selected houses in the HEEP sample in Auckland, Wellington, Christchurch, Dunedin, Invercargill, Whangarei and Tauranga, and in locations on the Kapiti Coast, Otago, Northland and Waikato. The estimates will be subject to change as wet-back water heating and solar water heating are included. The completed results of this work will be reported in the next available HEEP report.

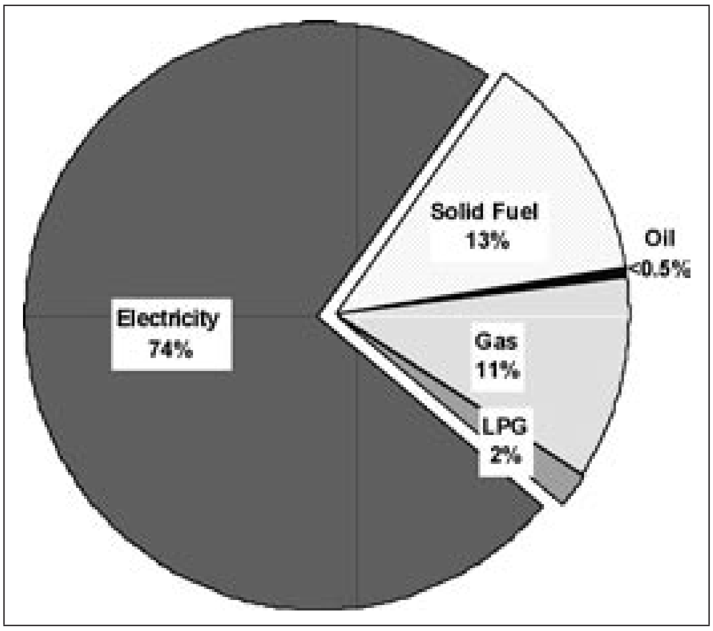

Fig. 9 Residential fuel use—preliminary HEEP estimate.

Figure 9 shows a preliminary estimate of the relative importance of the main residential fuels. Comparing the HEEP analysis in Figure 9 with the residential sector fuel use from the Energy Data File (Figure 4) shows a similar importance of electricity, but differences in that:

- no household geothermal energy use has been measured by HEEP (although this may relate to the specific sampling areas);
- HEEP monitored use of oil is lower than that suggested in the Energy Data File;
- solid fuel (coal and wood) and LPG are a higher proportion in the HEEP fuel use than in the Energy Data File (assuming “Other renewables” includes wood).

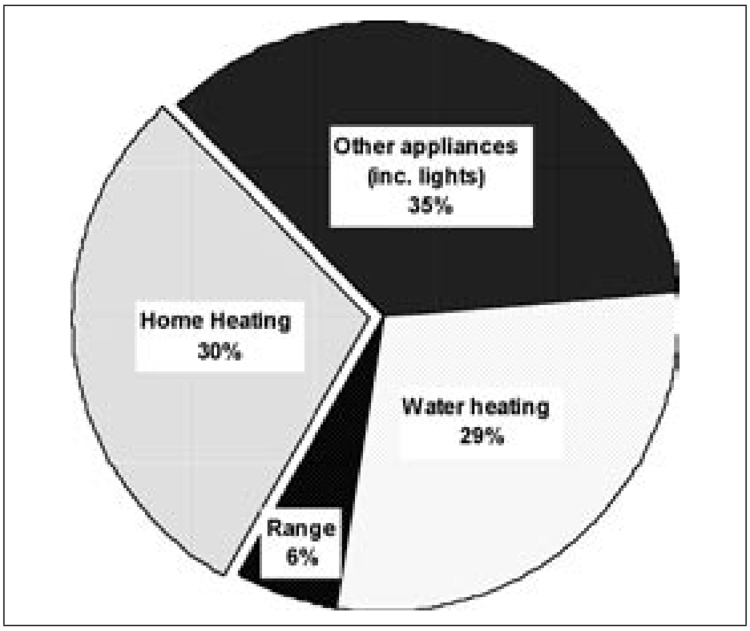

Fig. 10 Residential end-uses—preliminary HEEP estimate.

Figure 10 provides a preliminary estimate of residential energy use by end-use for the fuels in Figure 9. The proportional differences from electricity end-uses in Fig. 8 reflect the role of LPG, reticulated gas and solid fuels in providing space heating and domestic hot water.

Although it is possible to use different fuels for water and space heating, the shift is likely to occur over a long time period and be associated with consequential structural change. For example, "portable kerosene heaters" were found in 11% of households in 1984, but over the following 17 years have all but disappeared—only 0.6% of households had one in 2001. Similarly, "portable electric heaters" were found in 89% of houses in 1984, but by 2001 were only in 71% of households (Statistics NZ 2001). In most instances (as evidenced by the HEEP house appliance inspections), these heaters are no longer available for use. This would suggest that there are long-term energy supply planning implications of such shifts in energy end-uses.

These four figures illustrate how household energy end-use has changed over 30 years:

- Figure 7 (1971/72 Household Electricity Study) demonstrates for the first time that hot water heating, appliances and space heating were the major uses of electricity.
- Figure 8 (HEEP 2004 estimate based on the electricity use in 100 Auckland houses), illustrates how electricity use has changed over the past 30 years, particularly the increased importance of appliances.
- Figure 9 (HEEP 2004 estimate based on 300 mainly urban and suburban houses) illustrates the important role played by solid fuel (wood and coal) and LPG.
- Figure 10 (HEEP 2004) provides for the first time a preliminary understanding of all the energy end-uses in New Zealand houses.

The common theme in all of the end-use analyses is that heating fuels (space and water heating) are the drivers of household energy use, not the suggested "convenience appliances".

OPPORTUNITIES FROM UNDERSTANDING HOUSEHOLD ENERGY DEMAND

The exploration of the HEEP research into previously uncharted energy use has already given some important insights. The following examples are early results, and as the analysis progresses with the completion of the monitoring portion of the project, further insights can be expected. These examples illustrate the type of opportunities that result from improved understanding of energy end-uses. Most importantly, understanding of demand can be used to identify specific opportunities to deal with specific energy supply issues, rather than taking the simplistic option of reverting to investment in new supply.

Time-of-use profiles

Although the New Zealand electricity market has been based on half hour time-of-use profiles since April 1999, there is little evidence that tariff profiles are anything more than based on the shape of all the electricity consumed at the local grid exit point, minus the electricity consumed by commercial and industrial consumers. HEEP monitors all household fuels on at least a 10-minute basis, and can therefore generate time-of-use profiles for specific groups.

Domestic hot water—standing losses

The New Zealand Standard for the energy performance of domestic water heaters is based on laboratory testing, but the energy performance of hot water systems in actual homes is more complex and difficult to measure.

The energy used to provide household hot water relates to two issues: social (the amount of water used by people for different tasks); and technical (the energy used to heat water and maintain it at temperature). HEEP has quantified, for the first time in New Zealand, these two components:

- "Delivered hot water" represents the social portion of the energy use—the average use is between 4.2 kWh/day for electric night storage systems and 12.5 kWh/day for natural gas instanteous systems. This energy includes that used to heat the water that remains in the pipes after "use".
- "Standing losses" represent the technical portion of the energy use, and range on average from nothing for natural gas instantaneous systems (with electronic ignition) to an average of 4.1 kWh/day (27% of total gas use) for natural gas storage to an average of 2.6 kWh/day (34% of total electricity use) for electric storage systems.

Both the delivered hot water and standing losses vary from house to house, and from cylinder to cylinder, depending on a range of factors. These will include the cylinder size, age, insulation, thermostat type and water pressure, and the pipe material, insulation and length. HEEP is now exploring these differences, and those between fuel types.

Water conservation

There is an interesting inter-relationship between water and energy use. At the regional level, the provision of mains water involves a sizeable energy investment, principally in the form of pumping water from storage to the point of use. In the home, energy is used to raise the temperature of the water, so any action that leads to a change in hot water use will result in an increase in energy.

Traditionally New Zealand homes have been provided with "low pressure" hot water systems—often a copper hot water cylinder with a ceiling mounted "header" tank. Seventy-eight percent of the HEEP hot water systems are "low" pressure, with the remainder "mains" pressure. A major use of hot water is for showers, where the "length of shower" is measured not in water consumption, but by time. On average, "mains" pressure water systems have a higher flow rate than "low' pressure systems—averaging 10.6 litres per minute compared to an average of 7.2 litres per minute.

HEEP has been able to quantify the impact of a low-flow shower head on water and energy use based on actual measurements. In Auckland (where there are charges for both potable water supply and waste water removal), the savings from fitting a low-flow shower head would be of the order of $90 per year for one shower per day—or $360 for a four person household. About half of the financial savings are from water and half from energy savings.

Winter temperatures

New Zealand has a relatively mild climate—"temperate with sharp regional contrasts" according to the *CIA World Factbook* (CIA, 2003) —leading to the expectation that indoor temperatures are also temperate. The measured facts differ from this assumption.

HEEP has provided the first nation-wide data on the temperature patterns found in New Zealand homes. Current HEEP work suggests that the winter heating season includes the period between June and August (inclusive), and during this season the living room is heated in the evening between 1700 and 2250 hours. In the remainder of the house, and during the day, only minimal heating is used in most New Zealand houses.

The average winter evening temperature in the current 300-house sample follows a normal distribution, with an average temperature of 17.3°C and a standard deviation of 0.2°C. Importantly, about 28% of these average temperatures are below the healthy minimum of 16°C (WHO 1987). Further work is being undertaken to explore the reasons behind these heating patterns and resultant temperatures. These results will also be used to improve design guidance and thermal modelling tools.

Impact of thermal insulation

Houses built since 1 April 1978 are required to have minimum component levels of thermal performance, generally achieved by the addition of thermal insulation, but in some cases provided as an intrinsic part of the construction technology.

HEEP monitors the living room and bedroom temperatures. HEEP analysis has found that there is a relationship between the age of the house and the winter evening average temperatures. Based on the 400-house sample, we can conclude that living rooms in post-1978 houses are on average 1.0°C warmer (18.6°C compared to 17.6°C).

HEEP research has also found that households seldom heat bedrooms overnight, but post-1978 bedrooms are still 1.3°C warmer (14.5°C compared to 13.2°C), so this is achieved at no purchased energy cost—it is a benefit from the body heat of occupants and any energy using appliances, e.g., clock radio, lights, etc. It is possible that other issues are also important (e.g., different occupancy groups, house construction, etc) and this is being investigated.

Lighting and peak power

May 2004 saw the spectre of winter power outages in the top of the South Island as a result of potential peak demand electricity transmission capacity constraints. HEEP has identified lighting as a noticeable, but not major, use of household electricity. More importantly, HEEP has found that lighting is a significant component of peak electric power demand.

Peak lighting electricity use closely coincides with peak system power demand. Analysis of the HEEP database suggested that the peak lighting load was about 200 W per house. For the 230,000 houses in the area of the South Island expected to be subject to peak power constraints, this is a peak load of 47 MW.

The HEEP surveys showed that on average there are 20 incandescent lamps, one compact fluorescent lamp (CFL) and one halogen lamp in houses. Halogen lamps can not be simply replaced by CFL, as the fittings are not suitable. Of the 20 incandescent lamps, some will be in fittings that are not suitable for CFL, not all are high use, and some are not going to be used at peak times. A comparison of the average lighting power to the peak power load suggested that, on average, two incandescent lamps per house could be usefully replaced by CFL. This would reduce the peak power demand by 35 MW (i.e. from 47 MW to 12 MW) without reducing the service provided to house occupants.

The replacement of a 100 W incandescent lamp that is used all evening, with a 25 W CFL at an assumed cost of $10 (including GST and installation), will save the householder $16.38 per year. It will also have the effect of reducing peak electricity demand at a cost equivalent to $130 per peak kW. The capital cost of the incandescent lamps, assuming a service life of 1000 hours, is actually 50 cents higher than the capital cost of the CFL, also giving the householder a capital benefit.

In some houses more lamps could be expected to be "on" at peak times—in kitchen, living room, hallway, study, dining room—and these may provide additional peak power reductions, but would need to be considered on a house-by-house basis.

It is often argued that energy efficiency gains can be reduced by the behaviour of house occupants. In this case sunset in the top of the South Island is about 5 pm in winter, so if the house is occupied by 5.30 pm, the lights will be turned on thus ensuring the calculated peak power benefits will be obtained.

Appliances—standing by

Standby power is drawn by some appliances when not in operation but connected to the mains. Depending on the appliance type and age, the standby can range from zero (e.g., a non-electronic dryer with a clockwork timer) to 20 W or more (e.g., many televisions). These power consumptions may seem trivial (1W continuous is approximately 9 kWh per year and costs about $1.20), but since most households have many such appliances, the energy consumption may be a significant fraction of the total household electricity use.

Standby power also appears to be growing rapidly, due to the proliferation of electronic and computer controllers in appliances, and the increasing ownership of electrical goods.

The baseload electricity demand of a house is the typical lowest power consumption when there is no occupant demand. It includes the standby power of appliances (e.g., microwave ovens, VCRs, multiple TVs, video games, dishwashers, etc), plus any appliances that operate continuously (e.g., heated towel rails, clocks, security systems etc).

HEEP monitoring results were the first quantification of the impact of standby and baseload power for New Zealand houses. HEEP data suggest that standby and baseload power accounts for about 12% of household electricity—about 4% from heated towel rails, 5% from major appliances (e.g., washing machines, TV, etc) and the remaining 3% from a wide range of smaller or less popular appliances.

These results have already provided critical data to support the development of appropriate testing and Standards for Minimum Energy Performance Standards and Energy Labels. Further analysis can be undertaken of the HEEP data to better identify key growth areas, and their likely impact on the electricity system.

Faulty appliances

As the number of appliances in New Zealand homes increases, it is to be expected that some will fail. In many cases the failure will be obvious, e.g., the television fails to work, and the appliance will be replaced. However, the HEEP monitoring results are showing that when some appliances fail the failure mode does not alert the users to the failure. Such appliances may continue to consume more energy than necessary, but not provide the expected service.

For example, refrigeration equipment (refrigerators, refrigerator/freezer combination or freezers) use about 10% of household electricity. The HEEP survey has found that 55% of the refrigerators, 50% of the refrigerator/freezer combinations and 80% of the freezers are more than 10 years old (i.e. manufactured before 1994). This age is significant, as ozone depleting CFC refrigerants and blowing agents were phased out in 1994.

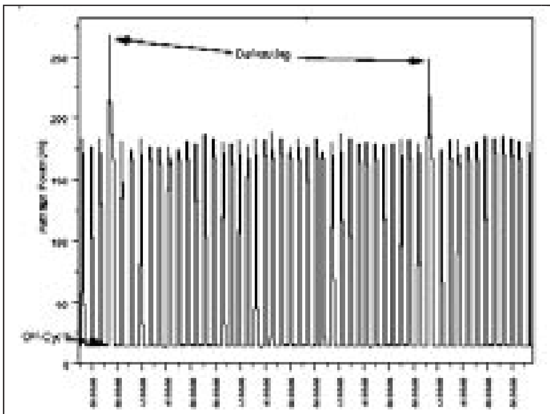

Fig. 11 Fridge—normal operation.

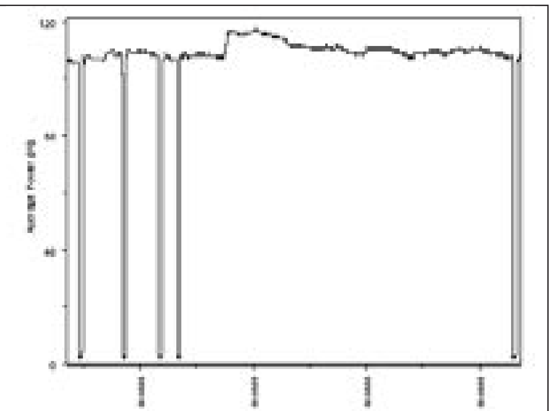

Fig. 12 Freezer—faulty operation.

What happens when refrigeration appliances fail? HEEP monitoring has found that nearly one in five refrigeration appliances have a problem—approximately 10% are faulty, with a further 8% are marginal. Nationwide, this is equivalent to over 400,000 appliances.

Figure 11 gives a typical example of the electricity use of a refrigeration appliance in normal operation. In this case, the compressor power is approximately 170 W, the off-cycle (baseload) power consumption is about 15 W, and defrosting occurs about once every three days.

An example of a faulty freezer is given in Figure 12, in which the compressor stays on for long periods of time and occasionally switches off. Some faulty refrigeration appliances never switch off.

Without the HEEP monitoring this issue would not have been either identified or quantified. The number of refrigeration appliances with problems is so large that there is an opportunity for real benefits—not only to the individual household (through improved food storage and energy savings), but also to the nation (through reduced electricity demand) and to the wider world (through correct identification of failure and recovery of the CFC gas).

HEEP estimates that each faulty refrigeration appliance uses about 550 kWh per year more than they would if operating properly—a cost of about $90 a year per appliance. Taking into account the faulty and marginal refrigeration appliances, the unnecessary expenditure could easily reach $30 million per year. If these appliances were replaced by modern appliances using half the energy of a correctly operating old appliance, the benefits could easily double.

DISCUSSION

Over 150 years ago, Charles Dickens' Mr Micawber neatly summed up the consequences of a mismatch between income and expenditure. We now must question whether today's society has learnt the consequences of an ever-increasing energy demand.

This paper has reviewed the availability of energy supply and demand data, and found that official statistics provide information on energy supply and sectoral energy demand. At the more detailed energy demand level, except for the residential sector as reported in this paper, the end-use data is out-of-date and inadequate.

Liquid transport fuel (in the main oil) was identified in the 1970s as New Zealand's main energy problem (e.g., Harris et al. 1977). Today, as the world looks towards a future with increasingly expensive petroleum-based transport fuels, we hold confidence in our abilities to deal with this, but based on a lack of knowledge of demand and a belief that investment in supply will be sufficient.

Can a society built on the assumption of readily available, low-cost oil continue without major change? For example, "just-in-time" manufacturing expects a flexible, responsive transport system to be able to deliver any required component within a well-defined timeframe. Such a transport system, in turn, is supported by low-cost fuel which can allow trucks (or cars) to travel with less than full loads.

In the main, sectoral energy demand changes slowly. Apart from step increases, for example due to the construction of a major base metals processing facility, changes in energy demand tend to be composed of a large number of small shifts. For example, the effect of more energy-efficient new houses and new appliances will take time to impact on the national averages. In the year ended August 2004, consents were issued for 32169 dwelling units (including 5942 apartments) (Statistics NZ 2004a). The average over five years (2000–2004) is 25534 dwelling units per year—which would take 62 years to completely replace the estimated 1.58 million private dwellings in New Zealand at 30 September 2004 (Statistics NZ 2004b).

The HEEP research is changing our understanding of household energy use. The preliminary analysis reported here shows that there have been critical changes in the demand for fuels over the past 30 years. For example, although total electricity use per household has not changed greatly, houses, households and the patterns of electricity use by these households have changed. The consequences of this shift have yet to be understood.

This lack of understanding can be traced to a lack of data, which in turn traces to a lack of investment in understanding energy demand. The majority of current New Zealand energy research is directed towards energy supply and conversion, and even energy demand statistics are in limited supply.

The HEEP work is providing new knowledge on the use of energy in the residential sector, and this in turn will provide significant opportunities—not only for energy supply but also for a wide range of other businesses involved in the provision of energy using and conserving products and appliances.

The examples presented here resulting from the HEEP improved understanding of household energy end-use include:

- possibilities of time-of-use profiles for different consumer groups;
- different importance of standing losses for different types of hot water cylinders;
- impact on energy and water costs of low-flow shower heads;
- patterns of heating and actual winter temperatures in New Zealand houses;
- impact of thermal insulation on living room and bedroom temperatures;
- importance of lighting on peak power demand;
- appliance "standby" power;
- importance of faulty refrigeration appliances.

In some cases these results come within the initial research goals, while in others they are a serendipitous discovery. The paper has provided examples of how the results of the HEEP research can lead to significant opportunities. How many other opportunities remain to be discovered is unknown, but then that is the objective of scientific research.

CONCLUSIONS

A budget advisor attempting to review New Zealand's energy income (supply) and expenditure (demand) would be faced with major difficulties—far more difficulties than faced by Mr Micawber with his detailed understanding of his pitiful situation.

There is a considerable knowledge of energy supply, but this is not the case for energy demand, although as a result of the research reported here we are beginning to better understand the residential sector. Although the residential sector only directly accounts for 12% of consumer energy, changes in the performance of this sector reflect throughout the economy.

The HEEP work, even though far from complete, has already identified a range of important energy demand issues in the residential sector that have important implications for national energy supply. These issues create new opportunities for science and business to create innovative solutions:

- What energy demand issues exist for other sectors in the economy?
- Could these energy demand issues result in improved or even in sustainable energy supplies?
- What are the opportunities to reduce the energy-related greenhouse gas emissions?

There are no answers to these and many other questions, as we as a society lack the basic knowledge. This lack of knowledge does not seem to be an appropriate basis on which to build a national energy policy.

Acknowledgements

The provision of data by the Energy Efficiency and Conservation Authority and the Ministry of Economic Development's Energy Modelling and Statistics Unit is gratefully acknowledged. My thanks to those who reviewed the initial draft of this paper.

The science reported here was funded by the Foundation for Research, Science and Technology. Data collection and analysis was supported by Building Research Levy, the Energy Efficiency and Conservation Authority, Transpower NZ Ltd, and a range of other sponsors.

The HEEP team is:

- BRANZ Ltd (Data collection and analysis) —Lynda Amitrano, Michael Camilleri, Lisa French, Nigel Isaacs, Andrew Pollard;

- CRESA (Social science)—Ruth Fraser, Kay Saville-Smith;
- CRL Energy Ltd (Modelling)—Pieter Rossouw;
- John Jowett (Statistical support).

This paper is respectfully dedicated to the late Dr Cam Reid (FRSNZ) and Mrs Kath Reid.

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World, regional, country and New Zealand electricity patterns

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ABSTRACT

This paper investigates the patterns of electricity consumption, electricity intensity, electricity intensity curves and electricity intensity factors for various regions of the world and the world total, and selected countries including New Zealand. It was found that the link between economic growth and electricity consumption is stronger in developing countries than those for industrialised countries. The paper also presents sets of forecasts obtained from electricity forecasting models for New Zealand and for the world total electricity consumption.

INTRODUCTION

Electricity is one of the most dominant forms of energy in human society. Its flexibility as an energy carrier has increased its share in total energy consumed in many countries. This has accelerated economic and social wealth in those countries, through technological innovation and adoption, and increased industrial production.

The heavy dependence of society on electricity requires planning of the resources for generation well in advance of consumption, to ensure a continuous supply of electricity in the future. This in turn requires measurement and determination of the patterns of electricity use to allow prediction of future consumption.

ELECTRICITY INTENSITY

Electricity intensity is one measure of the amount of electricity that is consumed in an economy as represented by the Gross Domestic Product (GDP). It is expressed as (Bodger 1984),

$$EI = \frac{Consumption}{GDP} \tag{1}$$

A number of underlying factors are reflected by changes in the ratio, such as the state of technology, the price of electricity, the composition of GDP, the levels of activity in individual electricity user sectors, and demographic and sociological factors. Although it is believed that economic growth and electricity demand are linked, the strength of the relation is different from region to region and depends on the stage of development of a country or region. A number of reasons may exist for changes in electricity intensity within a particular sector of industry. They include the growth or decline of electricity-specific end-uses, changes in their efficiency, increases in the use of electricity at the expense of other fuels, or the development of new electricity technology.

The electricity intensity curve (EIC) shows the stage of development of electrical energy in the process of GDP output (Bodger 1984). The EIC is obtained by graphing the electricity intensity and the level of average personal wealth in a country as measured by GDP per capita. The slope of the curve may assist in determining whether the electrical industry is in a growth, mature or ageing phase.

Each point on the EIC represents a combination of consumption, GDP and population for a particular year. This is called the electricity intensity factor (EIF). These points can be graphed against time. The EIF is defined as,

$$EIF = \frac{Consumption / GDP}{GDP / Population}$$

$$= \frac{Consumption \times Population}{GDP^2} \quad (2)$$

This paper investigates these patterns for regions of the world, world total and selected countries. The world data are divided into eight regions—North America (industrialised), Central and South America, Western Europe (industrialised), Eastern Europe and the Former Soviet Union (FSU), Industrialised Asia, Middle East, Africa and developing Asia. The selected countries for this study are New Zealand, United States, United Kingdom, Maldives, China, Japan, Russia, Germany, France, India, Indonesia and Brazil. Apart from New Zealand and the Maldives, all other countries are selected on the basis of being the largest populations, economies or electricity consumptions. The Maldives represents a relatively small developing economy.

WORLD REGIONAL ELECTRICITY PATTERNS

Figure 1 shows the electricity consumption in the eight regions of the world from 1980 to 2002.

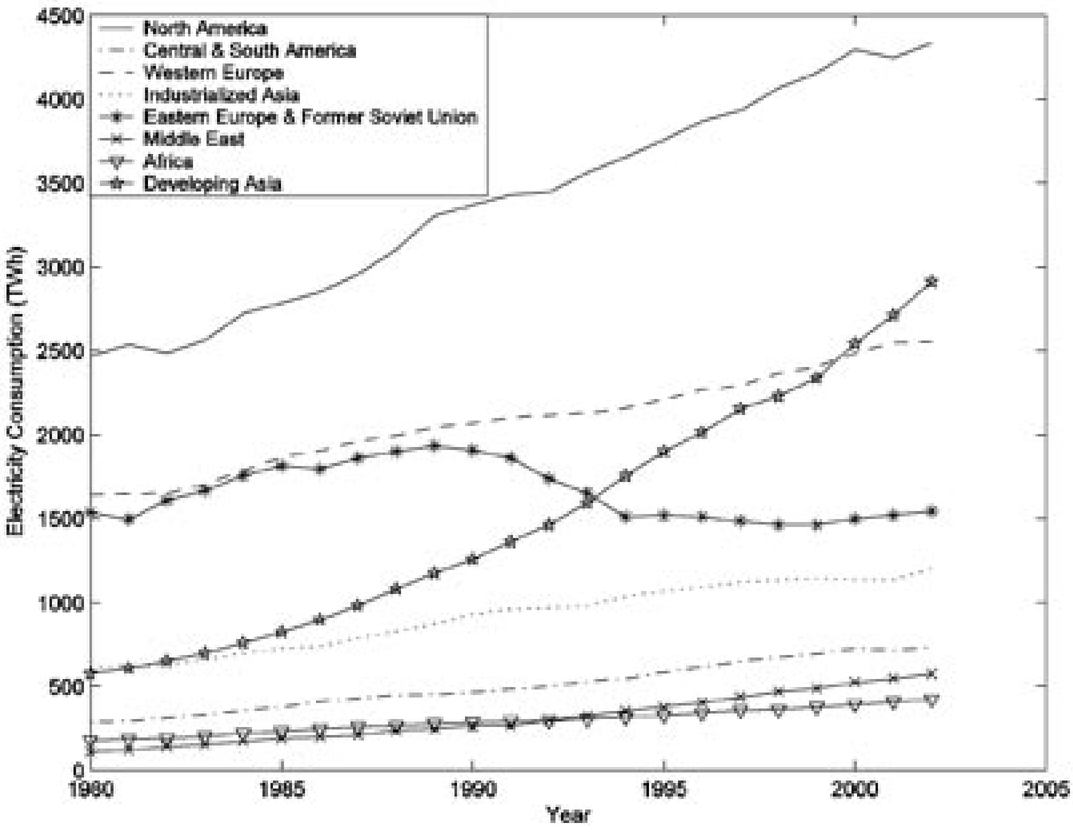

Fig. 1 Electricity consumption in the world (8 regions).

North America consumes the highest amount of electricity throughout the period and at 2002 this region accounts for about 30% of the world electricity consumption. Developing Asia shows the highest rate of growth and by 2002 this region is the second highest electricity consumer. Eastern Europe and the Former Soviet Union show recovery from the economic and social declines of the early 1990s. Africa and the Middle East consume the smallest amounts of electricity. The low electricity consumption in Africa with 14% of the world population indicates the low level of electrification in some countries of this region. In general the electricity consumption in the industrialised countries is increasing at a slower rate than those in the developing world.

ELECTRICITY INTENSITY IN THE REGIONS OF THE WORLD

Figure 2 shows the electricity consumption per capita for the regions of the world and the world total. The electricity consumption per capita is the highest for North America. The per capita electricity consumption has gradually increased for all regions except for Eastern Europe and the Former Soviet Union. This is mainly affected by decreases in electricity consumption due to the fall of the Soviet regime, the highest electricity consumer in this region. The per capita electricity consumption is the highest for the industrialised regions.

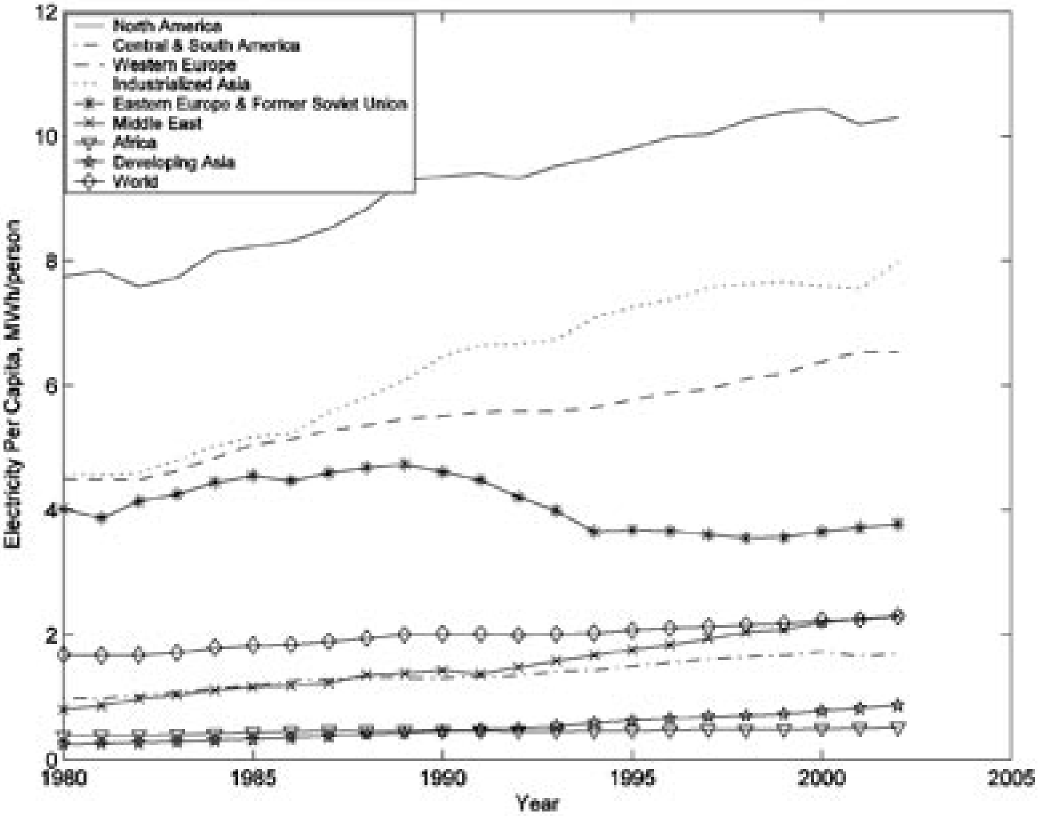

Fig. 2 Electricity per capita for the regions of the world and world total.

Figure 3 shows the corresponding per capita GDP for the regions. The wealthiest region is not necessarily the most energy-intensive. Industrialised Asia has the highest GDP per capita but it has got the second highest electricity consumption per capita. The high GDP per capita is due to that of Japan as compared to Australia and New Zealand in this region.

Figures 4 and 5 show the electricity intensity for the regions of the world and the world total. The electricity intensity in Eastern Europe and the Former Soviet Union is the highest and most variable. There is a sudden decrease in the early 1990s reflecting the break up of the Soviet Union and its transition from a centralised planned system towards a more free-market economy. However, even after the fall of the Soviet regime, this region has still got the highest electricity intensity with a decreasing trend.

The developing regions of the world reflect an increasing intensity over the years. The fastest growth is observed in the Middle East. Irrespective of these trends, the world average electricity intensity has been at a near constant level of around 0.4 kWh/US$ (1995) for more than 20 years, reflecting the dominance of Industrialised Asia, Western Europe and North America which display very constant levels over the period.

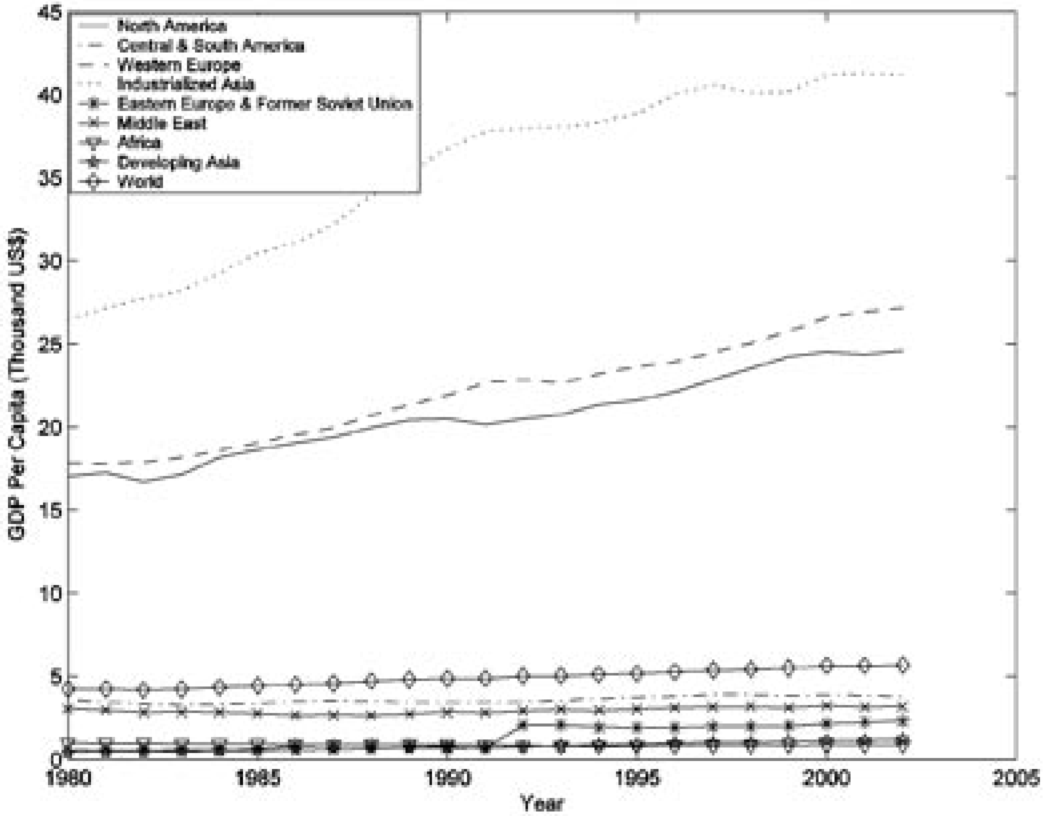

Fig. 3 GDP per capita for the regions of the world and world total.

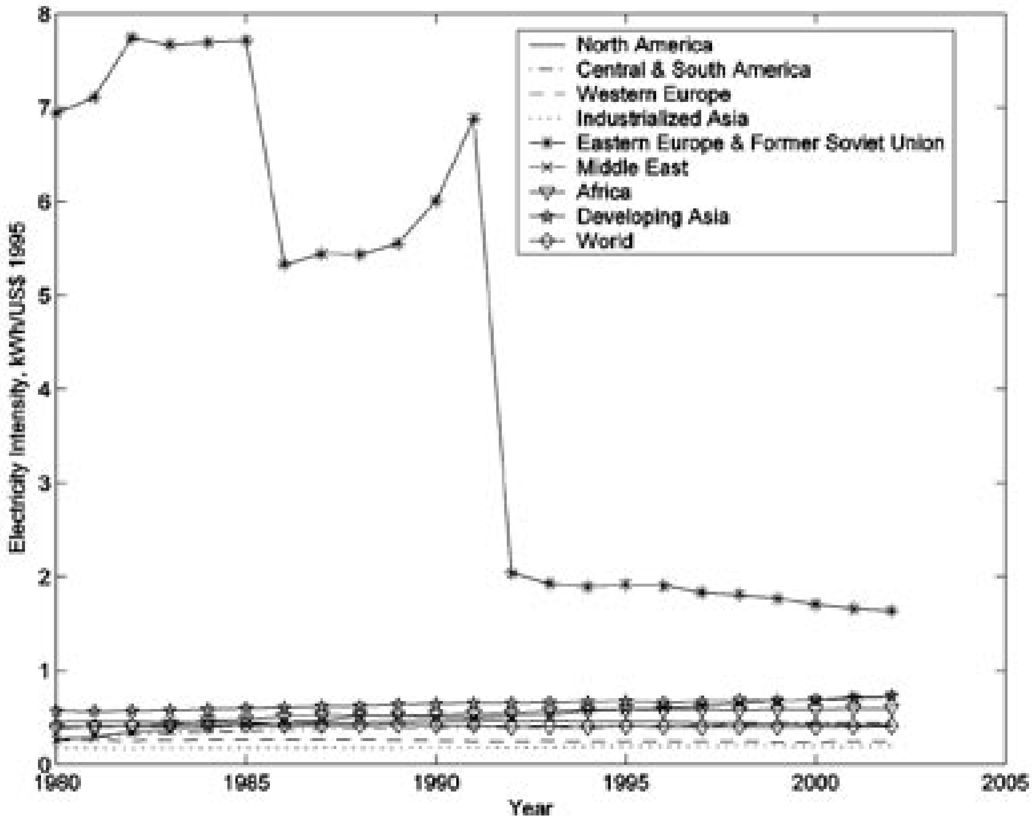

Fig. 4 Electricity intensity for the various regions of the world.

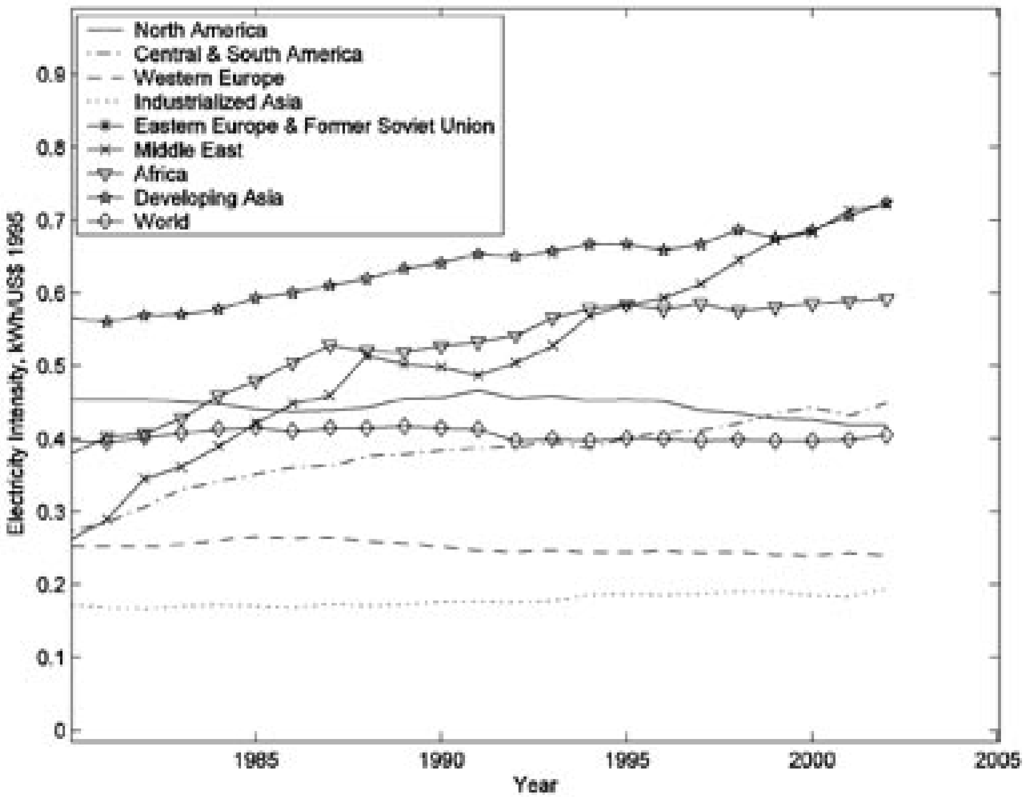

Fig. 5 Electricity intensity for the regions (Figure 4 enlarged).

The electricity intensity curves for the regions of the world are shown in Figure 6.

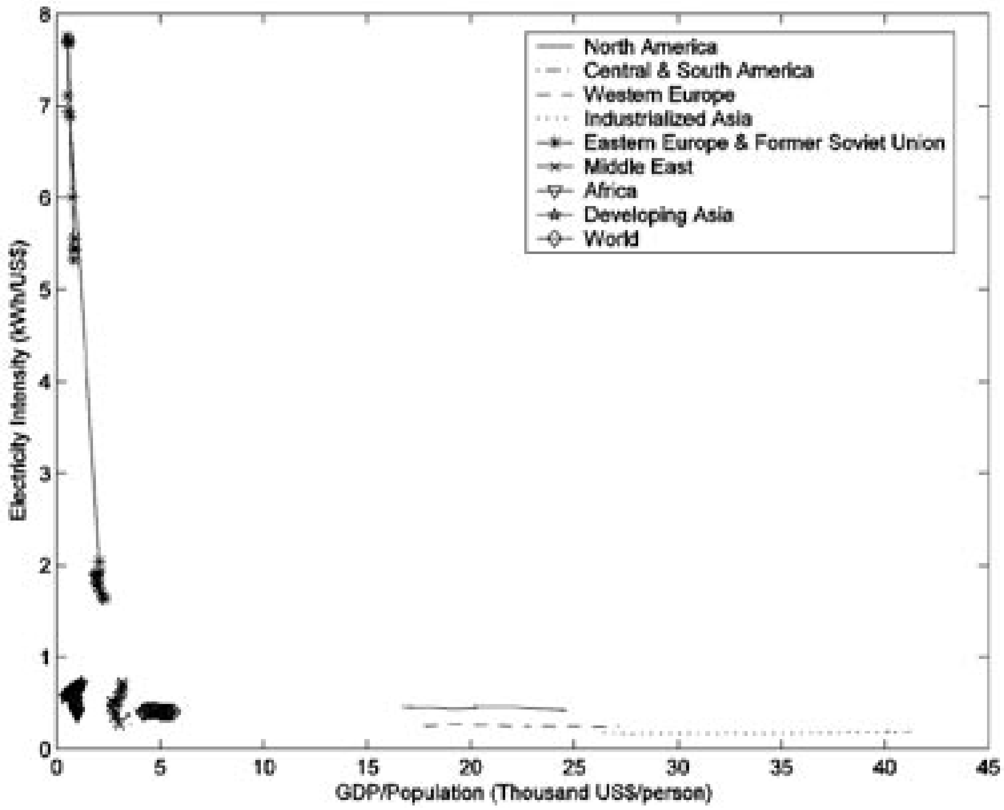

Fig. 6 Electricity intensity curves for the regions.

A significant gap between the income levels of industrialised regions of the world and the developing world can be observed. The intensity curves for North America, Western Europe and Industrialised Asia are almost horizontal indicating that the economic wealth is achieved without changes in electricity intensity. By contrast, in the developing regions, the per capita GDP is nearly constant and is independent of electricity intensity. The curve for Eastern Europe and the Former Soviet Union is much higher than all the rest. The world average reflects the industrialised regions being horizontal with relatively low values of EI for low wealth per person.

Figure 7 shows the electricity intensity factors for the regions of the world. Eastern Europe and Former Soviet Union has the highest intensity factor which is rapidly decreasing. The electricity intensity factors for Africa and Developing Asia appear to be converging to a similar level. The intensity factors for the industrialised regions are very low, comparable to each other and at very constant levels over the years. The intensity factors for all the developing regions are above the world average whereas those for the industrialised regions are below the average.

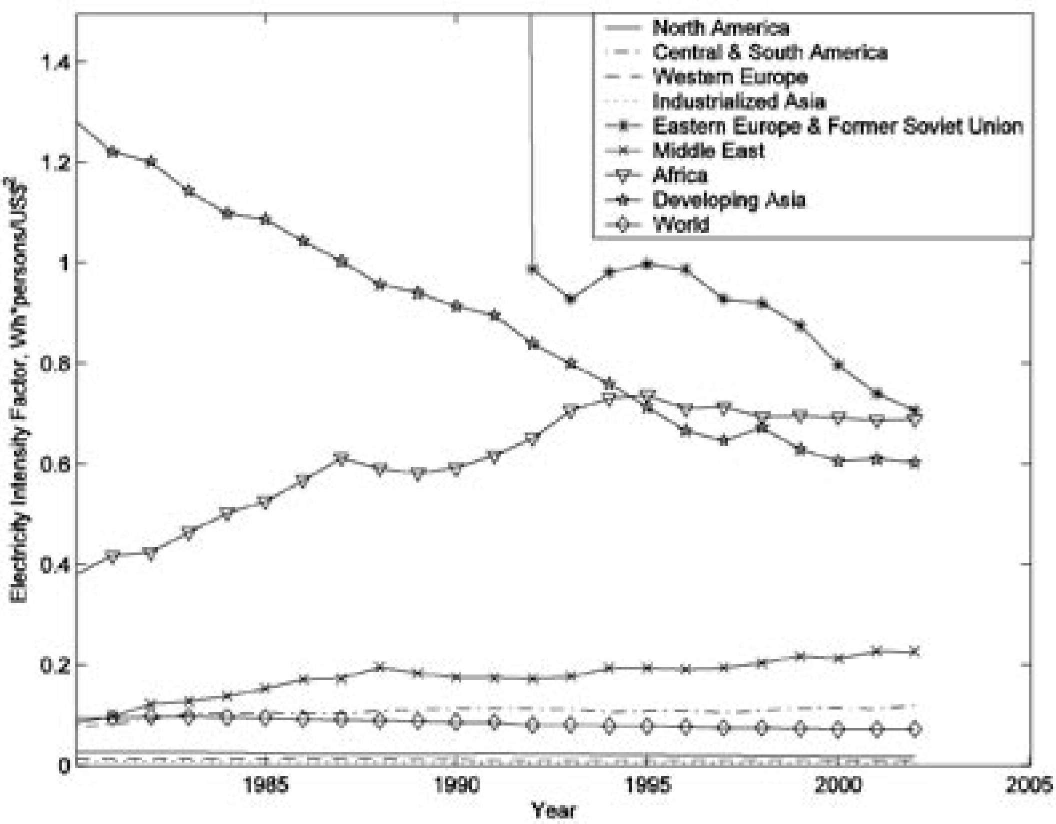

Fig. 7 Electricity intensity factors for the regions of the world.

ELECTRICITY INTENSITY IN SELECTED COUNTRIES OF THE WORLD

In this section, the relationship between electricity consumption, GDP and population of 12 selected countries are analysed. Figure 8 shows the electricity consumption per capita for these countries. This is highest in the United States while New Zealand consumes the second highest amount of electricity per person. The electricity consumption per capita in the industrialised countries of the United Kingdom, Japan, Germany, France and Russia are very similar. The electricity consumed in the developing countries is very low compared to the industrialised countries.

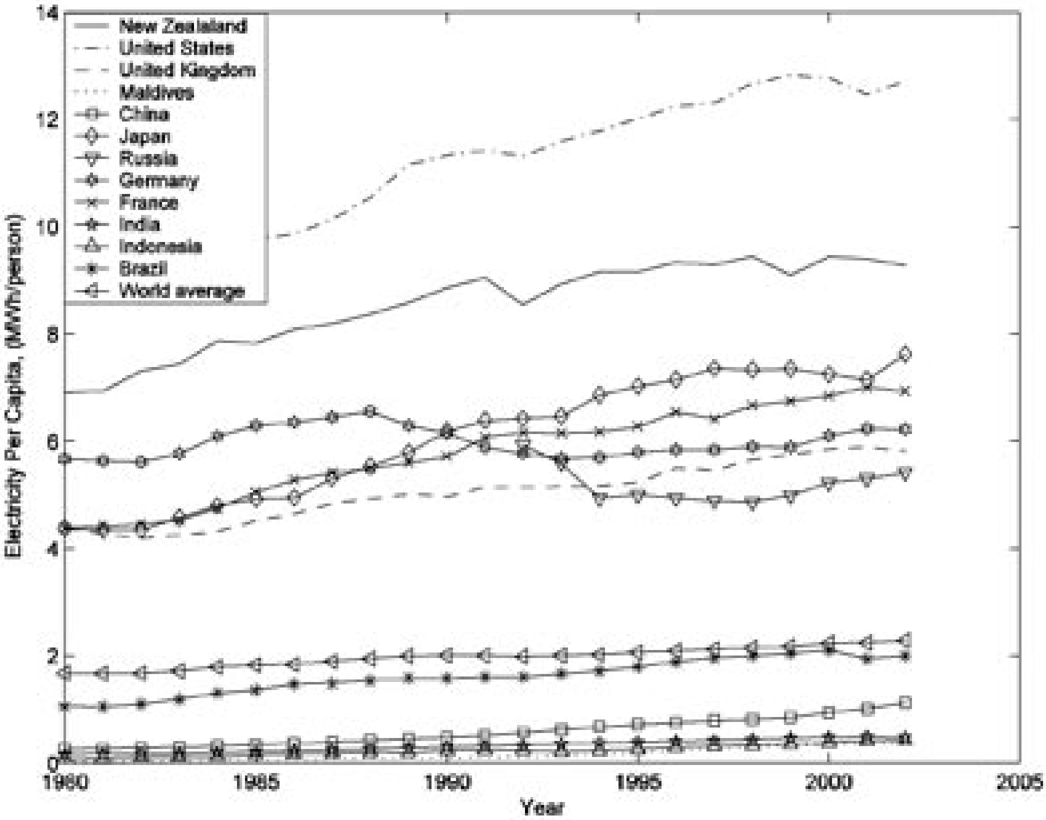

Fig. 8 Electricity per capita for the 12 countries.

Figure 9 shows the GDP per capita for the 12 countries. Japan shows the highest GDP per capita of the 12 countries presented. The GDP per capita for United States, Germany and France are next with United Kingdom and New Zealand showing very similar patterns throughout the period. The GDP per capita for the developing countries are the lowest.

Figure 10 shows the electricity intensity in these countries. The electricity intensity is highest in Russia. China and India are next. New Zealand has the fourth highest electricity intensity throughout the period. For the other countries, the difference in electricity intensity is small although Indonesia has had a large variation over the period.

The electricity intensity curves for the 12 countries are shown in Figure 11. The curves are spread out along the two axes. There is a distinguishing pattern in the curves of the industrialised countries and the developing countries. The industrialised countries with high income per capita generally have relatively constant low consumption per dollar of GDP. The developing countries with low, relatively constant, income per capita, have low to high levels of consumption per dollar of GDP. In general, the electricity intensity factors for the industrialised countries have decreased over time. The electricity intensity factors for New Zealand are the highest over the whole period, whereas the United States and the United Kingdom have similar levels. Japan shows the lowest electricity intensity factors. The sudden drop in electricity intensity for Germany from 1992 is because electricity consumption data for Germany after 1992 include those for West and East Germany.

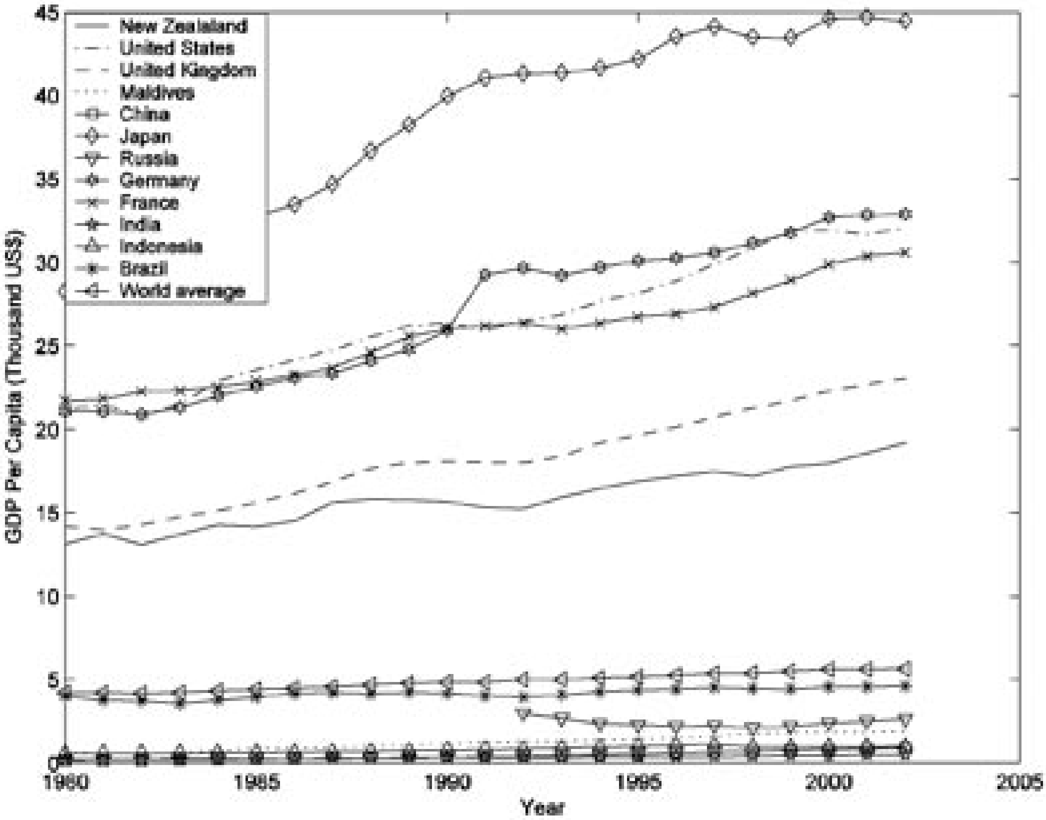

Fig. 9 GDP per capita for the 12 countries.

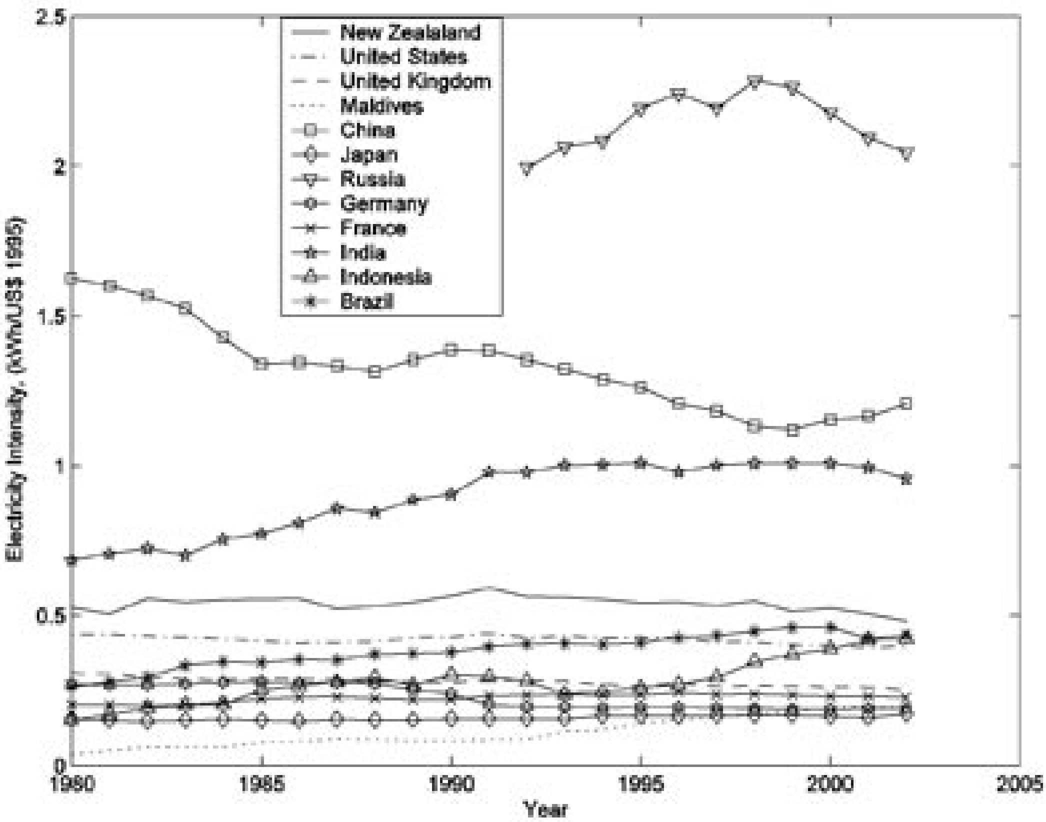

Fig. 10 Electricity intensity in the selected countries.

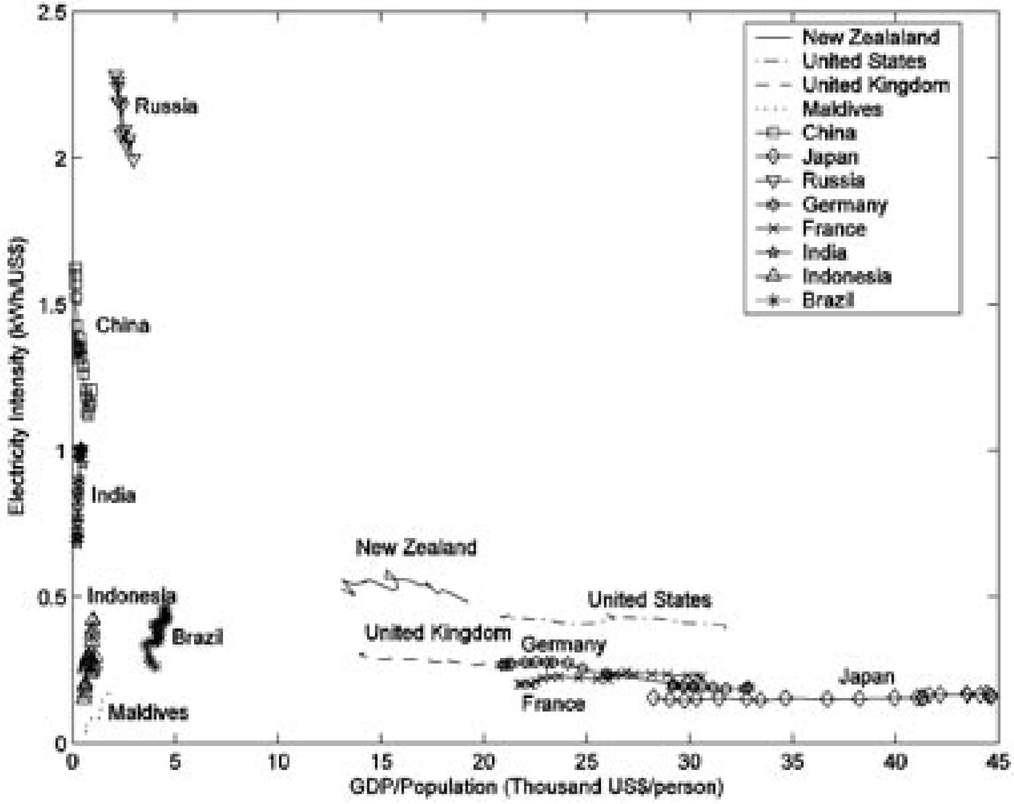

Fig. 11 Electricity intensity curves for the selected countries.

Figure 12 shows the electricity intensity factors for the industrialised countries.

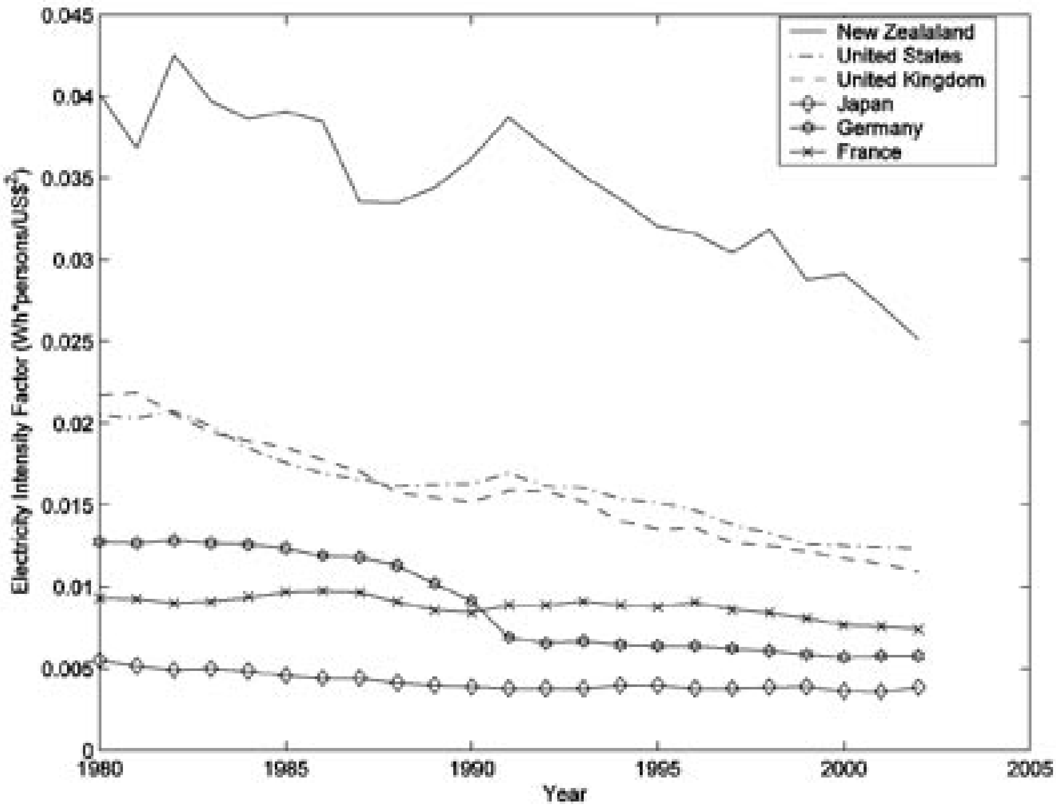

Fig. 12 Electricity intensity factors for the industrialised countries.

However the GDP data for East Germany before 1992 were not available. Therefore, the GDP data for Germany before 1992 are less than they should have been because of the unavailability of this data. Overall, for the industrialised countries the electricity intensity factors are converging.

Figure 13 shows the electricity intensity factors for the developing countries. In China, the EIF has decreased dramatically. In India, the factor has decreased slightly over the years. Overall the electricity intensity factors appear to be converging in a similar manner to those for the industrialised countries, but to a much higher level.

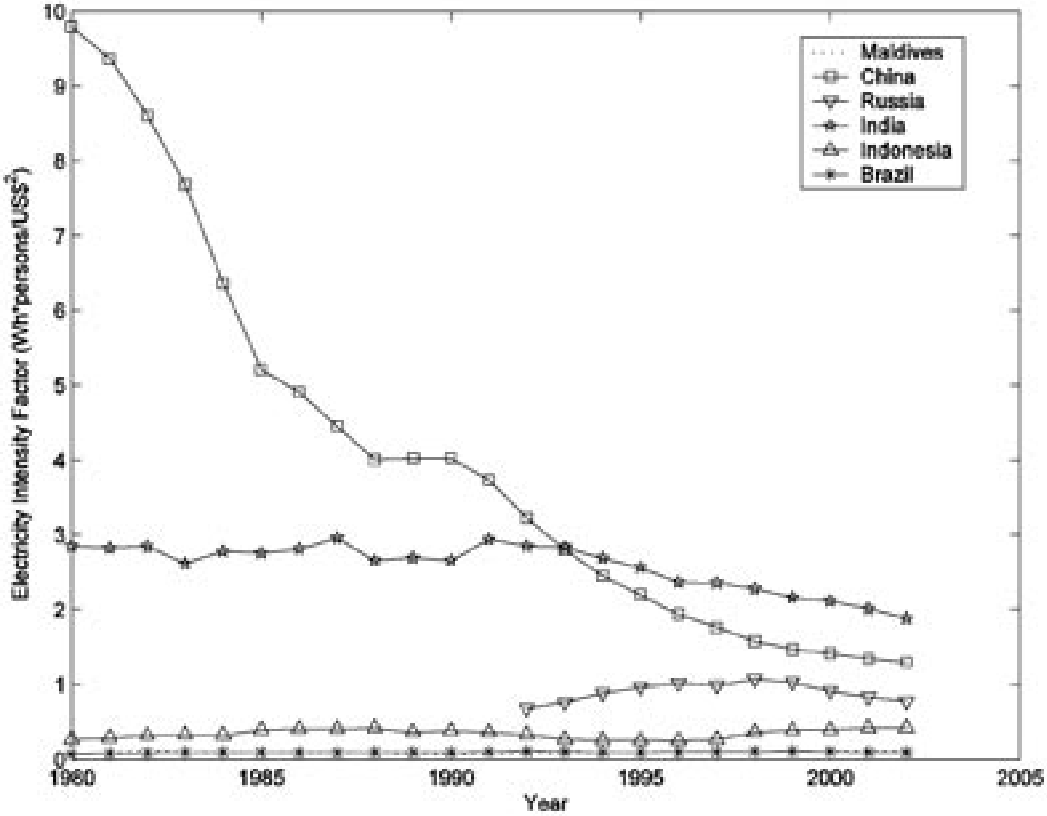

Fig. 13 Electricity intensity factors for the developing countries.

The electricity intensity, and thus the electricity intensity curve and electricity intensity factors, is higher for New Zealand than the other industrialised countries. The high electricity intensities in some countries have been explained with regard to availability of inexpensive hydro capacity (Nilsson 1993). Hydroelectricity accounts for 55% of the total electricity generated in New Zealand whereas the next competing industrialised country, France, has only 14% of its total electricity generated using hydropower. On the other hand, the other industrialised countries have a significant percentage of nuclear, whereas the developing countries have little. Perhaps as China and others develop, this energy source may be used further.

The high electricity intensity in New Zealand relative to other industrialised nations may also be the result of high electricity consumption in residential homes. In general, electricity is used for all residential purposes including water heating, air conditioning and cooking. In many of the developed countries natural gas is used for water heating, room heating and cooking. New Zealand's high electricity intensity may also be due to the electricity intensive industries (EIIs) such as aluminium smelter, steel and pulp, and paper mills.

Electricity prices and relative fuel prices play an important role in locating electricity-intensive industries, and the choice of energy carrier and space heating (Nilsson 1993). However it has been found that the electricity price does not affect electricity efficiency significantly in the household and service sectors (Nilsson 1993). This is supported by the fact that the energy intensities in several countries have continued to decrease when energy prices have been falling.

WORLD TOTAL FORECASTS

Figure 14 shows the world total electricity consumption. The pattern is smooth and increasing indicating that it can be modelled independently from all factors other than time.

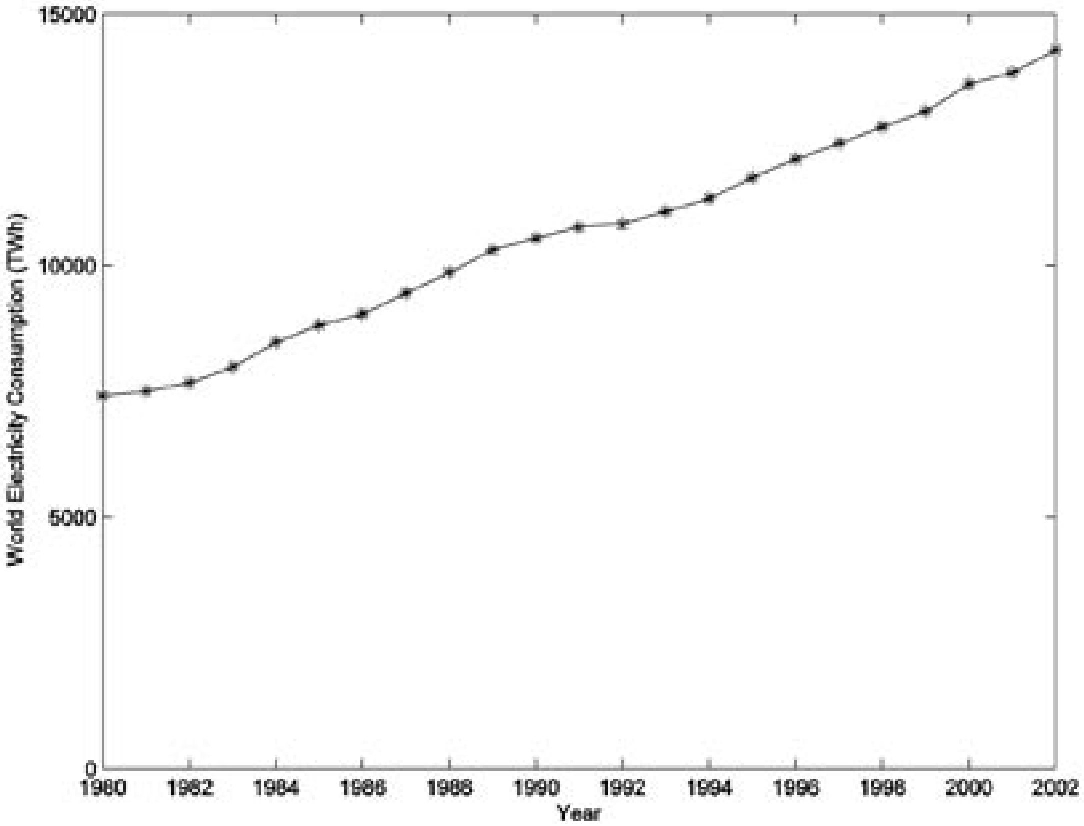

Fig. 14 World total electricity consumption from 1980 to 2002.

Six electricity forecasting models have been developed and applied to electricity consumption (Mohammed & Bodger 2003; 2004a, b, unpubl. data). They are the Logistic model, Combined model, autoregressive integrated moving average (ARIMA) model, Harvey Logistic model, Harvey model and Variable Asymptote Logistic (VAL) model. They are all variations of time series extrapolation techniques. Figure 15 shows the world total electricity consumption as forecasted using five of the models. The VAL model was not applied to the world data because off the availability of a limited number of data points. The Logistic, Combined and ARIMA models gave relatively similar forecasts for 15 years ahead. The Harvey model predicted the highest rate of consumption.

It is expected that much of the growth in electricity demand in the world would come from the developing countries. Although the developing countries account for more than 75% of the world population, the electricity consumption in these countries is only one-third of the world's electricity consumption (EIA 2004). The developing countries are expected to have a robust economic growth in the coming years. This requires access to reliable supplies of electricity. As a result, various strategies have been implemented such as privatisation to increase investment in the electricity industry and enacting government policies to encourage investment from potential foreign participants (EIA 2004). In addition, rural electrification schemes are expected to be introduced both to improve the standard of living and to increase the productivity of rural communities. The growth in electricity consumption in the industrialised world is expected to increase more slowly. The mature electricity sectors and gains in equipment efficiency in the industrialised countries are expected to slow down the growth in electricity consumption.

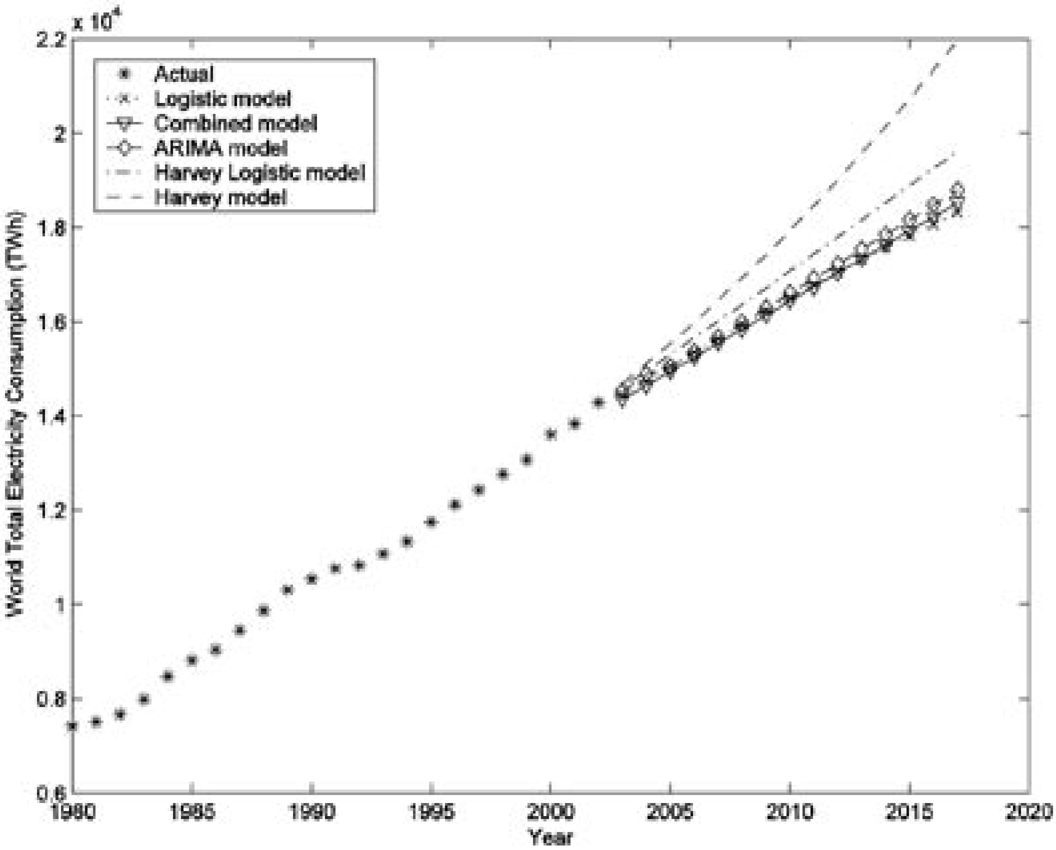

Fig. 15 Comparison of forecasts for world total electricity consumption.

Despite these expectations it is not necessary to know their details for modeling as the combined effect is that electricity consumption is increasingly independent of them. The impact on energy resource requirements to generate the electricity consumption is obvious as is the generation of byproducts that affect the environment.

FORECASTING ELECTRICITY CONSUMPTION IN NEW ZEALAND

Electricity intensity in New Zealand

Figure 16 shows the electricity consumption for New Zealand from 1943 to 1999. The electricity consumption data are divided into Domestic and Non-Domestic sectors. There is an increasing trend in the consumption data for all the sectors. The patterns have been relatively smooth despite the myriad of factors that might be considered as influences. These factors are not needed to model the patterns. In terms of larger trend changes, the rate of consumption growth is generally very slow in the Domestic sector especially from 1975 onwards. It is considered that during the early 1970s domestic electricity consumption grew rapidly mainly as a result of the conversion to electric space heating, the near universal use of electric water heating, and the widespread use of appliances such as washing machines and television sets (Ministry of Energy 1984). However, during the late 1970s electricity consumption dropped noticeably, attributed to a downturn in the economy combined with high electricity prices (Ministry of Energy 1984). Coal and natural gas attracted some of the demand. The effect of restrictions on electricity use brought about by the prolonged drought sequence from November 1991 to June 1992 can be clearly seen on all sectors, with a sudden decrease in electricity consumption for 1992.

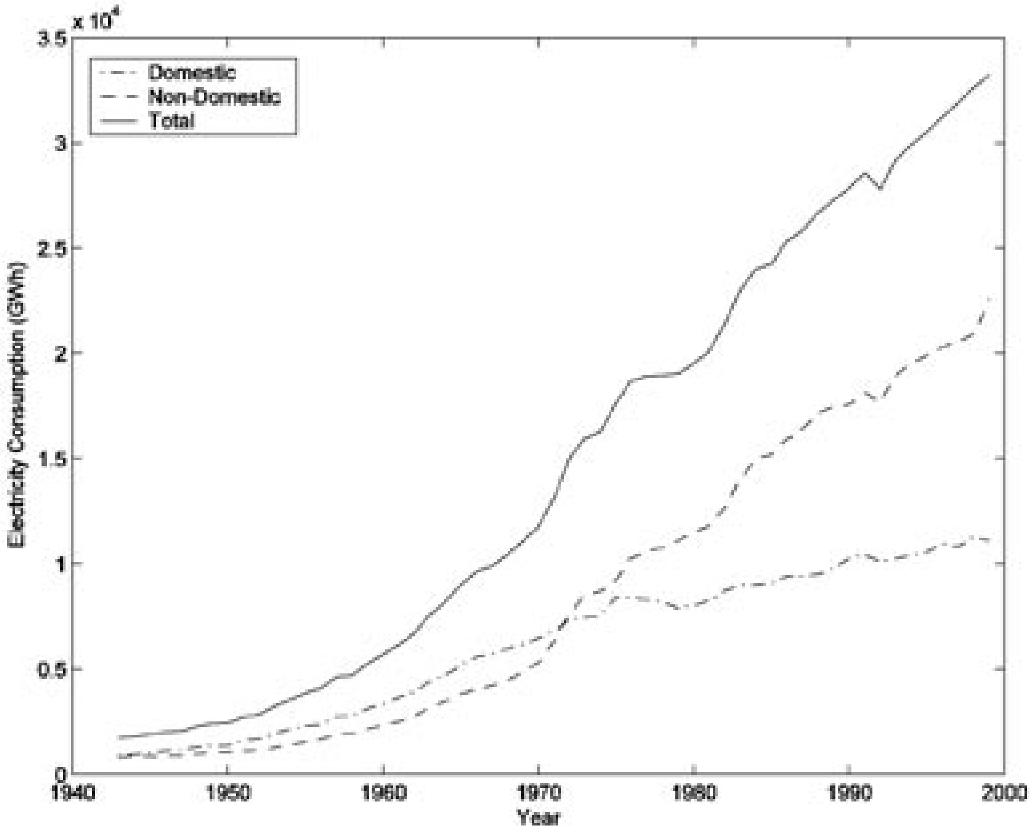

Fig. 16 Electricity consumption in New Zealand.

Figure 17 shows the electricity per capita, electricity intensity, electricity intensity curve, and electricity intensity factors for New Zealand from 1980 to 2002. The per capita electricity consumption has increased except in the last few years. The electricity intensity has peaked around 1991 and has been declining in the latter years. The electricity intensity curve is similar, indicating that the electricity industry in New Zealand has gone through the early phase of growth, matured and is now in the ageing phase. The electricity intensity factor in New Zealand has decreased over the entire period indicating a reduction in intensity per unit of wealth creation. Electricity is declining in importance relative to economic wealth.

Deregulation of the New Zealand electricity industry

New Zealand began with the process of deregulating its electric power industry in 1987 aiming to transform the country to a greater free-market economy. In 1993, a transmission corporation was created and monopolies in local distribution and retailing were eliminated. A new electricity policy designed to create a competitive electricity market was also issued in 1995.

The Electricity Industry Reforms Act 1998 required electricity distribution companies to separate line and supply business by 31 December 2003 (MED 2003a, b). Most companies decided to retain their lines business and sell their retail business. TransPower, a state-owned transmission system enterprise, is responsible for operating the national grid and to contract with users for new investment opportunities (MED 2003b).

The Electricity Industry Bill was passed in August 2001. The Bill amended the Ministry of Energy Abolition Act 1989, the Commerce Act 1986, the Electricity Act 1992 and the Electricity Industry Reforms Act 1998. The Commerce Amendment Act 2001 allowed the Commerce Commission to control the price revenue of electricity line businesses and to take over the administration of the electricity information disclosure regime. The Electricity Amendment Act 2001 allowed the government to establish by Order as a Crown entity, an Electricity Governance Board and provided the government with the power to make regulations on a number of matters like the requirement to

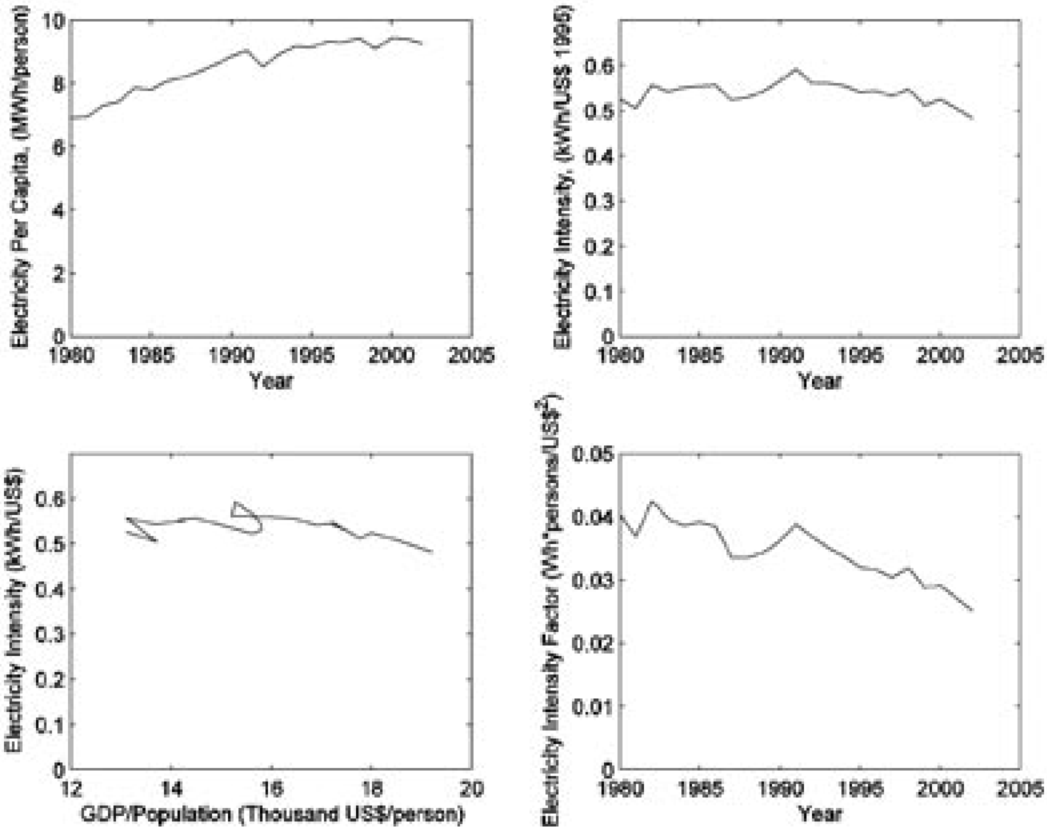

Fig. 17 Electricity per capita, intensity, intensity curve and intensity factors for New Zealand.

provide domestic consumers with a low fixed charge tariff option (MED 2003a). The Electricity Industry Reform Amendment Act 2001 relaxed the rules on the ownership of the electricity generation by line companies and enabled unlimited ownership of renewable generation. The sale and purchase of wholesale electricity in New Zealand is organised by the participants in a private sector wholesale market (MED 2003a).

Despite these amendments, reforms and changes, deregulation has had no significant effect on the electricity consumption patterns in New Zealand in the long term. Price variation, one of the reasons deregulation was introduced, has had no long-term effect on the patterns either.

New Zealand forecasts

In New Zealand, electricity consumption forecasts have been published by the Centre for Advanced Engineering (CAE) (Sinclair Knight Merz and CAE 2000) and the Ministry of Economic Development (MED 2000). These and the forecasts obtained by all the developed models mentioned earlier in the paper, from the year 2000 to 2015 for the Domestic, the Non-Domestic and the Total electricity consumption, are shown in Figure 18–20 respectively.

For the Domestic sector, the highest forecasts are given by the MED and the CAE models. The best of the developed models based on data fit accuracy is the Harvey model which gave forecasts in the mid range of the spread.

For the Non-Domestic sector, the CAE model and MED model forecasts are again very similar and compare with forecasts obtained from the Harvey Logistic model, which was the most accurate model fitted to the Non-Domestic data.

For the total consumption, forecasts given by the Harvey model are very comparable with the CAE and the MED model forecasts. A comparison of the accuracies by the six developed models for New Zealand indicated that the Harvey model is the most accurate model to fit the actual

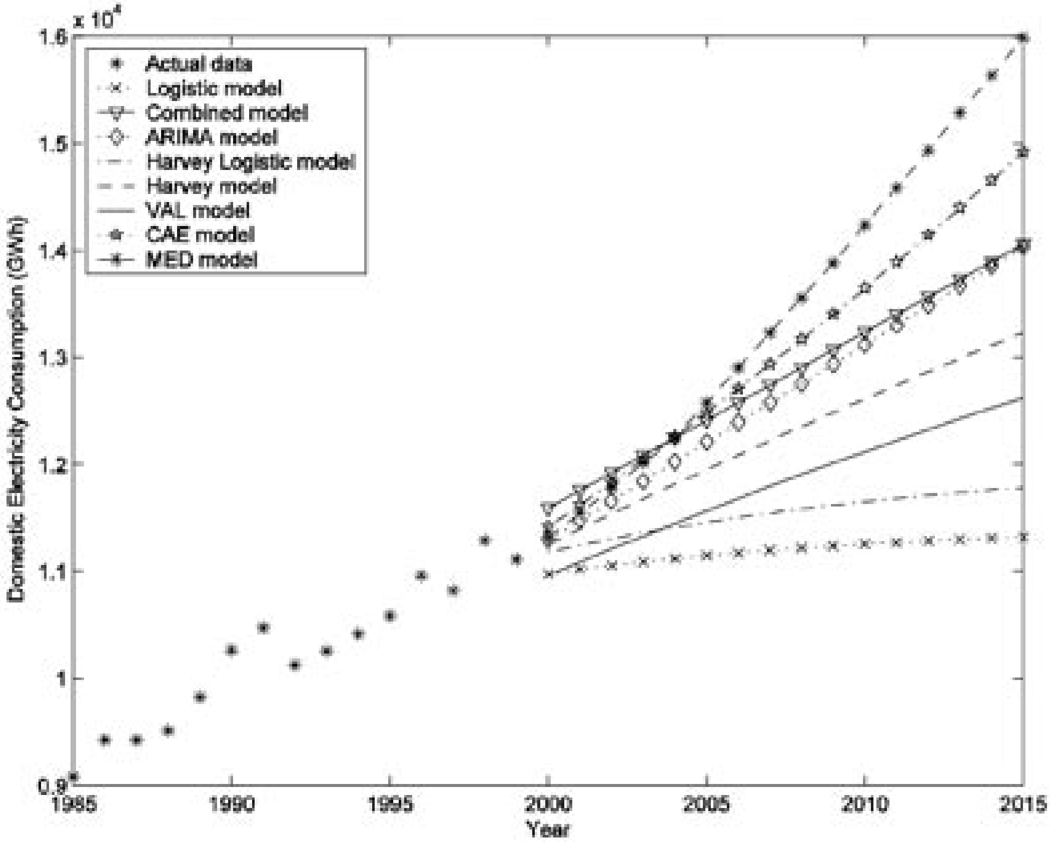

Fig. 18 Comparison of forecasts for Domestic sector of New Zealand.

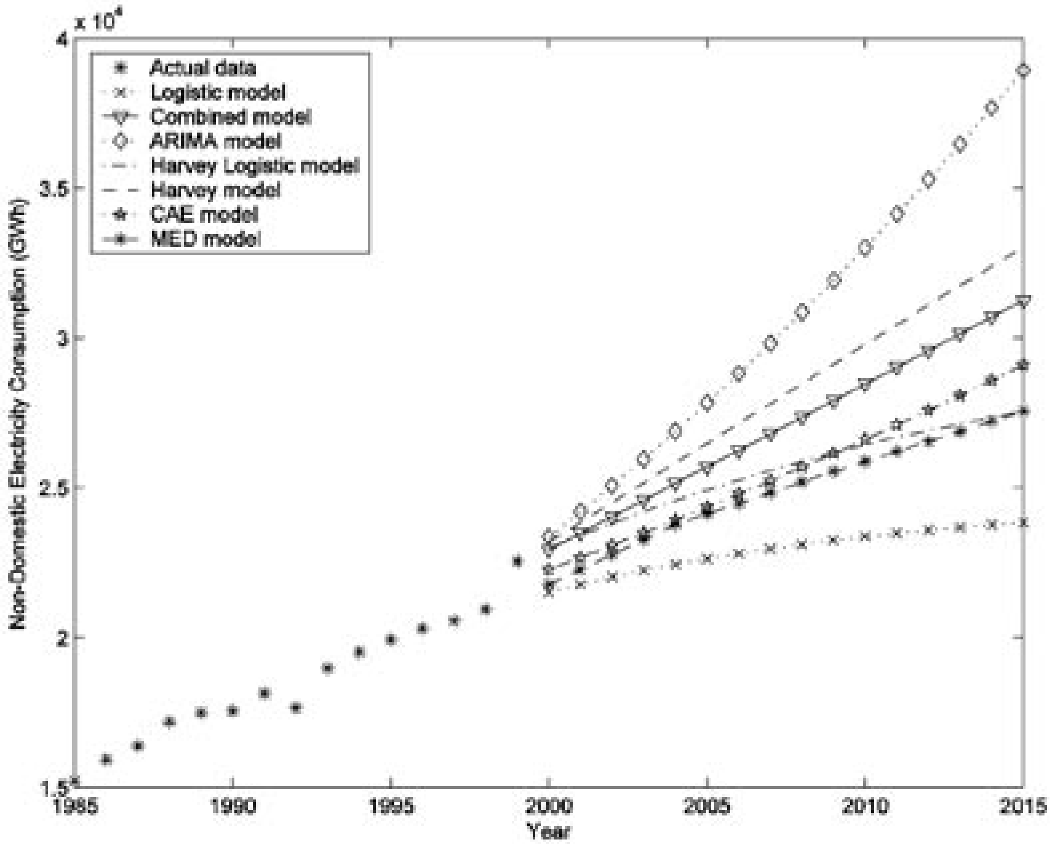

Fig. 19 Comparison of forecasts for the Non-Domestic sector of New Zealand.

data. This model gave an average error of just over 1% over the historical data, whereas the second best model (ARIMA) gave a 1.5% forecasting error for the total electricity consumption of New Zealand. This analysis has revealed that while ARIMA and regression techniques using economic and demographic factors are well known in electricity forecasting, the simple growth curve models are as accurate and hence may play a significant role in forecasting electricity consumption.

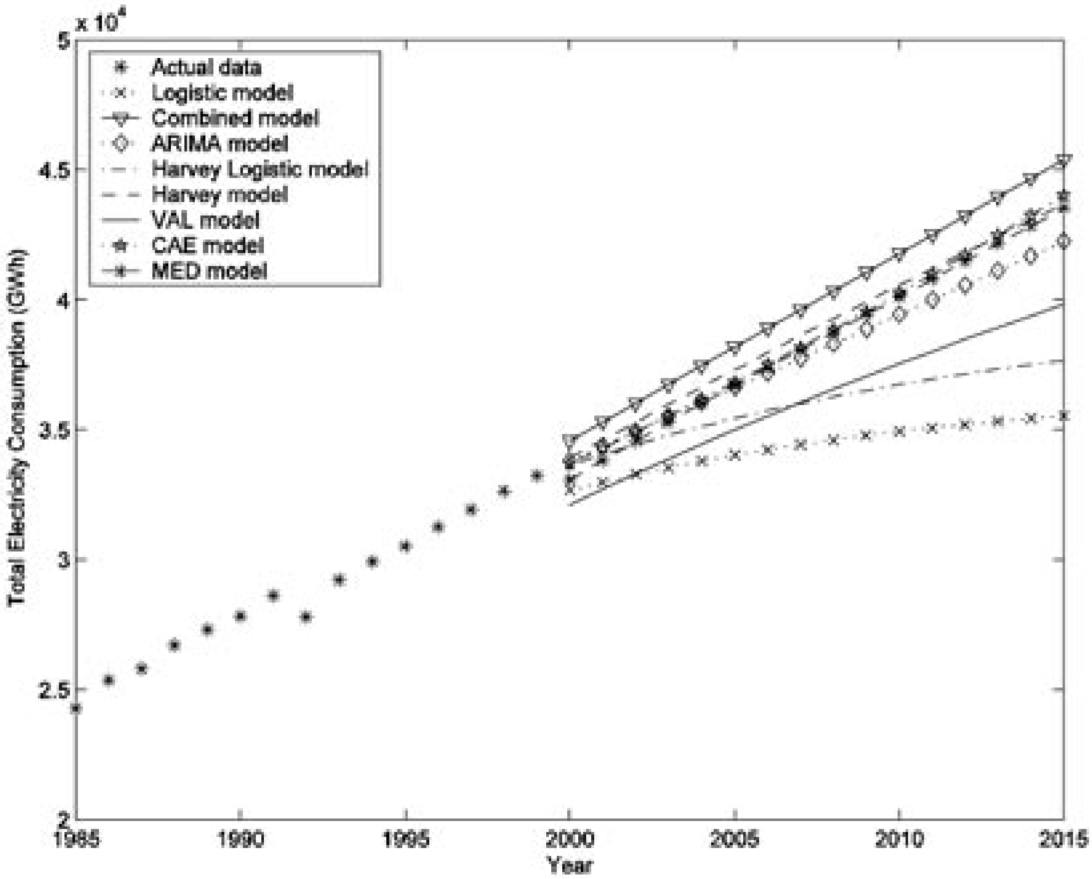

Fig. 20 Comparison of Total electricity consumption forecasts for New Zealand.

CONCLUSIONS

This paper has investigated the patterns of electricity consumption in the regions of the world and selected countries of the world. The relationship between economic growth and electricity consumption has been investigated using electricity intensity, electricity intensity curves, and electricity intensity factors. The link between economic growth and energy demand is strongly influenced by the stage of the development and the standard of living in a given region. The link between economic growth and electricity consumption was found to be stronger in developing countries than those for industrialised countries. In the developing countries, the economies grow as more new industries that generally contribute to economic wealth emerge. In the industrialised countries, although the energy consumption remains high, energy use is more stable or slowly changing. In addition, the chances for increased efficiency, as a result of replacing old equipment with modern equipment, in the industrialised countries are higher than those for the developing countries. This has contributed to a reduction in the energy intensity of the industrialised countries. A general trend of a decreasing intensity in the industrialised countries and increasing intensity in the developing countries has also been observed.

The paper has also presented the special case of New Zealand electricity consumption. Forecasts by some developed models are presented to show what the electricity consumption in the world and New Zealand could be in the future.

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The challenge of consumer energy efficiency

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INTRODUCTION

By providing increased energy service from the same purchased energy, improved consumer energy efficiency has the potential to contribute to the decoupling of economic growth and energy demand. It is now well accepted that more efficient energy use will become more important in the future under increasingly tight environmental and energy resource constraints. This paper analyses the growing dichotomy between supply-side and demand-side solutions to global energy and environmental problems by assessing the relevance of energy consumer efficiency, the barriers to improved efficiency and the measures presently used to overcome these barriers. Although much of the discussion is applicable to energy systems in general, the paper focuses primarily on electricity in New Zealand. Opportunities for resolving the asymmetry between supply-side and demand-side options are considered, including the possibility of a new energy security market to address both energy efficiency and supply security issues.

ELECTRICITY DEMAND AND SUPPLY IN NEW ZEALAND

Electricity consumption in New Zealand is 35–40 TWh per annum (pa) at a cost of some $3.5 billion pa to consumers (MED 2004). Figure 1 shows the growth of residential, commercial and industrial electricity use since the mid 1970s. Over this time, total demand increased at an average rate of 2.7% pa, significantly faster than the rate of population increase, 0.8% pa.

Traditional sources of supply extension in New Zealand include large-scale hydro, conventional thermal power and combined cycle gas turbines (CCGT). The large-scale heritage-hydrostations, built during the mid 20th Century, together with the abundance of locally sourced natural gas, allowed New Zealand to price its electricity at the low end of the international spectrum. To service continuing demand growth reliably, however, these traditional options present difficulties. There are uncertainties surrounding resource consents for hydro and the availability of natural gas for CCGT plants is in question. Apart from Project Aqua, which has been set aside in the meantime, new hydro generation is expected to be priced above current wholesale prices (6–7 c/kWh) (MED 2002). As a substitute for generation based on Maui gas, power produced by imported liquefied natural gas is priced by Contact and Genesis at 6.8–7.5 c/kWh, based on a national scale of operation (Contact Energy 2004) which is still relatively high. While large supply extensions are currently feasible using renewable generation, such as wind, or using fossil fuels, such as coal, they will only come into use at higher prices (MED 2002). Coal generation will be subject to carbon charges under the Kyoto Protocol.

Marsden et al. (2004) reinforce the expectation of future price rises, pointing out that wholesale prices are presently inadequate to secure investment in new generation. These suggestions, in combination with two exceptionally "dry" years in 2001 and 2003, raise concerns about whether the electricity market is able to maintain adequate levels of supply security in the face of growing demand. Similar concerns about the adequacy of investment in electricity production and networks, especially in liberalised markets, are echoed internationally (Borner et al. 2003; Vries 2003).

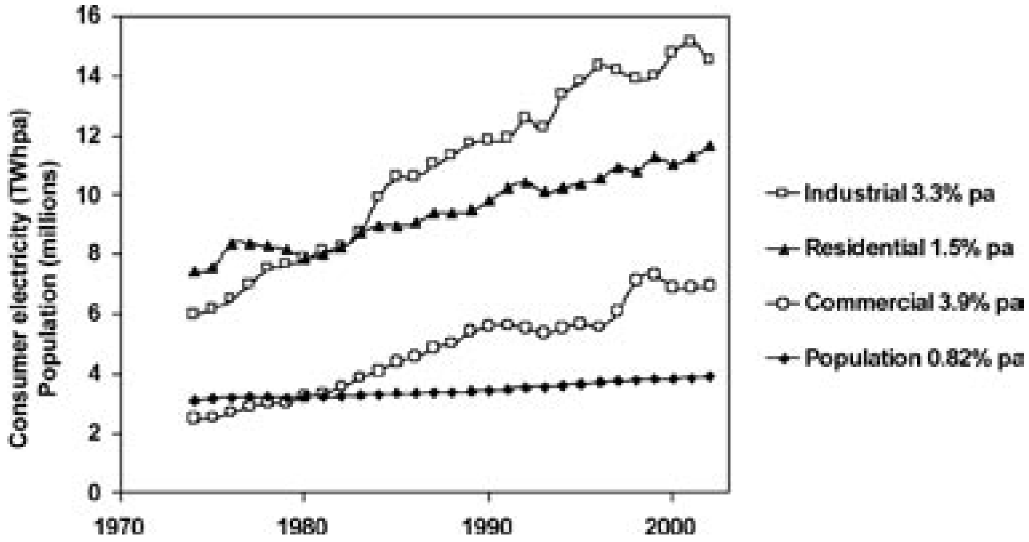

Fig. 1 Medium-term growth in electricity use and population in New Zealand, after MED (2004).

Long-term investment decisions for generation are taken primarily with a view to the beneficial interests of the investor, without necessarily considering the impact on overall system security (Borner & MacKerron 2003). They note that there is no direct market for security of supply nor are there adequate long-term instruments to act as a proxy for this market. The current market incentives for investing in the reserve generation required to underwrite supply security are either high spot prices in periods of shortage or long-term contracts. Because of the absence of a short-term demand response mechanism for many consumers, spot prices can be extreme during a shortage and yet still not fully reflect the value consumers place on the load. Long-term contracts are rare since liquid electricity futures markets do not exist for the timeframes required to hedge price risk for generation projects and, with the advent of competition at the retail level, suppliers cannot expect to pass this price risk directly to consumers (Helm 2002). Further, there is little incentive for individual consumers to contract for grid-connected reserve generation as the additional reserves/security benefits the entire grid (Vries 2003). There is also a risk that the Government will intervene to underwrite overall security when it is at risk, as is already happening in New Zealand under the new Electricity Commission.

While there is evidently a trade-off between maintaining energy price stability and ensuring energy security, progress can be made toward both goals by managing demand growth. Improved consumer efficiency provides a path which can moderate growth in consumer energy demand without necessarily reducing economic growth. For New Zealand, consumer efficiency offers an opportunity for smoothing its transition away from hydro-generation and low-cost Maui gas to other more expensive sources.

To illustrate the effect of this transition, Figure 2 shows, for 24 OECD nations, the relationship between the average national price for electricity in $US per kWh and the structural electricity intensity, expressed in kWh per $GDP in $US. The figure uses data published by Verbuggen (2003). The fitted curve, which is close to hyperbolic, shows that as prices increase, OECD economies tend to have lower electricity intensity. Currently New Zealand's economy has a relatively high electricity intensity, due to the relatively low electricity prices. In its transition away from heritage-hydro and Maui gas, New Zealand is therefore likely to move to the right, down the curve, as higher prices place pressure on its most electrically intensive industries. Higher prices will test the economic viability of these industries and could lead to their departure from New Zealand, resulting in a restructured economy with lower electricity intensity.

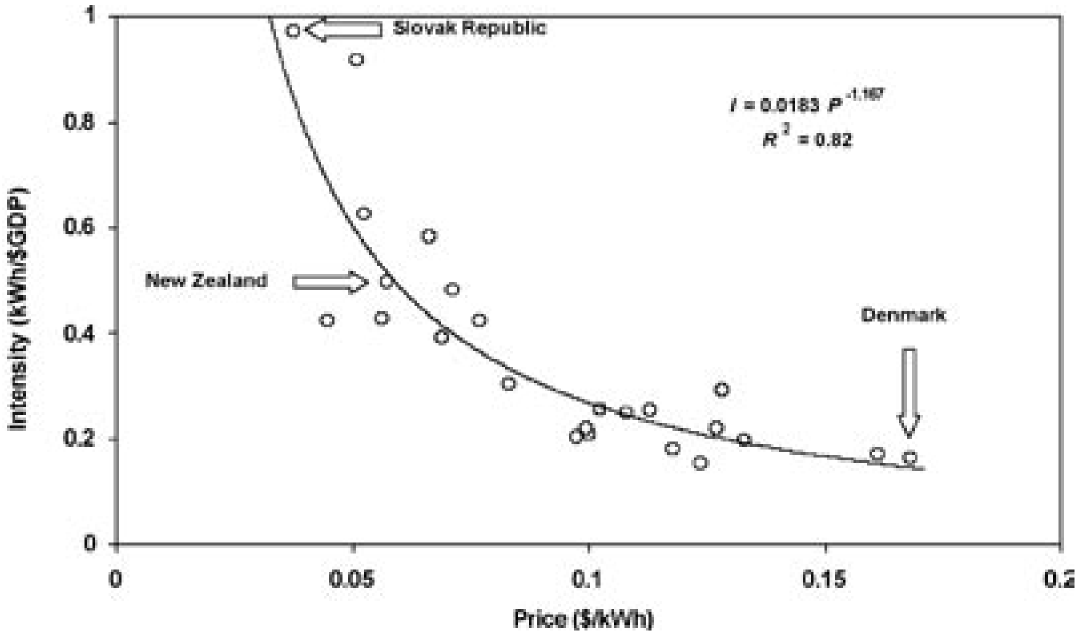

Fig. 2 Intensity-cost curve for electricity in 24 OECD nations, after Verbuggen (2003).

DEMAND MANAGEMENT

As a response to the shortage of reserve generation capacity, reducing inefficient demand instead of increasing supply will diminish the need for investment in both generation and transmission. This is important, since the cost of supply extensions will tend to decrease with time as new generation and transmission technology is developed further and matures with technological learning. In addition, demand reductions provide the opportunity to avoid many of the negative environmental consequences associated with supply extensions.

The potential to reduce inefficient demand has long been recognised. The Ministry of Energy (MOE 1986) 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". Some 15 years later EECA (2001) suggested that "…within individual business or institutions energy efficiency improvements of 15–25% are typically achievable over three to five years." Internationally the message is the same. Cowart (2001) stated that " … as much as 40% to 50% of expected [US] load growth over the next 20 years can be met through end-use efficiency and load management, cost-effectively and reliably". Taking a global perspective, the World Energy Outlook (IEA 2004) included an alternative scenario in which countries are assumed to implement the energy efficiency and environmental measures currently under consideration. These measures include encouraging energy efficiency as well as altering the fuel mix towards more environmentally benign sources. Under this scenario primary energy demand would be 10% lower and CO_2 emissions 16% lower than the business-as-usual projection by 2030. Increased energy efficiency is responsible for 58% of the reduction in CO_2.

Two points emerge from the IEA analysis. First, energy efficiency measures can have a discernable and significant impact on both energy demand and carbon emissions. Second, improved energy efficiency transfers the need to invest across the meter from the supply to the demand side. Both the alternative and the reference scenario have similar total levels of investment, since the increase in investment required by consumers is offset by a decrease in investment on the supply side. In the alternative scenario the obligation to make some $2.1 trillion of capital investment would move from suppliers to consumers. This raises two questions (IEA 2004). Do consumers have the ability to make this investment? Are there sufficient incentives for them to do so?

The costs of increasing consumer efficiency will be predominately incurred by the consumer, with the return being received in the form of increased service from the energy purchased. Although this reduces the amount of energy purchased, it can nevertheless be argued that the consumer is receiving only some of the benefits of their investment since decreased energy demand results in avoided supply. In the electricity sector this benefits grid security, as there will be greater reserves and therefore greater reliability. Thus it can delay the need for investment in both network and generation capacity (Horii et al. 2001) which in turn delays the associated environmental effects. Hence the consumer investment in energy efficiency has many non-rival benefits.

THE REBOUND EFFECT

It is important to distinguish between reduced energy demand and improved consumer efficiency. Consumer efficiency is the ratio of the energy service received by the consumer to the energy required to provide that service. This differs from demand reductions, which are reductions in the amount of energy consumed compared to a business-as-usual baseline. Increasing consumer efficiency will lead to demand reductions only if demand for the underlying energy service does not increase proportionately more than the increase in efficiency. Thus when the purchase price for electricity is constant, an increase in consumer efficiency naturally leads to a decrease in the "implicit" price of the energy service. This can lead to some of the demand reduction due to increased consumer efficiency being "taken back" (Greening et al. 2000). First, consumers will be inclined to substitute a proportion of other, now relatively more expensive, services for the increased efficiency service. Second, a reduction in expenses leads to an increase in net income, which is likely to be spent on energy consuming products. The size of the short-term income effect in New Zealand can be expected to be small. Less than 3% of any increase in income can be expected to be spent on consuming more electricity, based on the current proportion of household spending on electricity (Statistics New Zealand 2001).

Table 1 Short-term rebound effects in the US, after Greening et al. (2000).

Residential space heating	10–30%	Residential hot water	10–40%
Residential space cooling	0–50%	Lighting	5–20%

Table 1 lists values for the short-term rebound effect obtained by Greening et al. (2000) for US consumers. This data indicates that short-term rebound effects can erase some demand reductions, but for many energy services significant demand reductions do actually occur. However there is little empirical evidence on long-term rebound effects. Verbuggen (2003) notes that relative expenditure on electricity in the OECD countries appears to be almost constant at 2.5–3% of GDP and is independent of price and consumer efficiency. From this viewpoint, improved consumer efficiency would be essential to enable consumers to obtain the same level of service in the face of price increases. On a macro-level there is significant debate about the effects of increased consumer efficiency (Saunders 2000; Schipper & Grubb 2000; Brookes 2004). An increase in prices either artificially, through taxes as in the Netherlands, or through rising supply costs, as is likely in New Zealand, will naturally mitigate any rebound effects.

BARRIERS TO ENERGY EFFICIENCY

Regardless of the degree to which improved consumer efficiency results in demand reductions, the current level of end-use efficiency is below the cost-effective levels obtained from engineering and economic models (Jaffe & Stavins 1994; Sanstad & Howarth 1994; Weber 1997). The reasons for the disparity between realised efficiency and the economic potential for efficiency are complex. Many barriers result from organisational or behavioural factors arising from the human dimension, which can be difficult to overcome.

DeCanio (1993) discusses bounded rationality due to the organisational structure of firms, focusing on the dislocation of individual and collective interests, the satisficing rather than maximising nature of investment decisions (Simon 1957), asymmetric information, and moral hazard—where one or more parties involved in an agreement have incentives to act contrary to the principles of that agreement. Particularly pertinent is management myopia, as a result of compensation being tied to short-term performance and rapid rotation of management staff. This biases capital decisions towards short payback projects. Furthermore, with firms making satisficing decisions, small cost-cutting projects often lack attention because of the effort and expense of information gathering and decision-making relative to the payoff.

Robinson (1991) focuses on the consumer rather than the firm and suggests differing social status, feelings of competence, interest in technologies and general culture can all affect the level of energy use. Erickson (1987) finds that cultural and political differences between Sweden and the US are important variables in explaining the differences in their energy use. Economic analysis views the energy users as investors but Stern & Aronson (1984) suggest that viewing energy users as consumers or members of a social group, and energy consumption as an expression of personal values, provides a better understanding of the actions of individuals. 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. These factors frequently bias decisions against energy efficiency or in some cases eliminate improved energy efficiency from consideration.

Many would argue that, with organisational and behavioural barriers, it is the role of an astute entrepreneur to overcome them. On the other hand, many of these barriers are underpinned or exacerbated by information problems associated with energy efficiency. Information has many public good aspects, which affects its availability adversely. Consumer efficiency, which induces energy savings, benefits society through the public-good aspects of avoiding pollution and environmental damage, as well as supporting supply security. There is therefore a case for public intervention.

Because many barriers are associated with information relating to energy efficiency, these are considered here in more detail. Huntington et al. (1994) assert that informational problems are the primary reason the market for energy efficiency fails to produce the level of consumer efficiency indicated by the cost-effective potential. 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 (Jaffe & Stavins 1994; Sanstad & Howarth 1994). As a consequence transaction costs are increased because consumers must expend greater effort in gathering, assessing and applying information. Even if a consumer decides to purchase a more efficient product and is satisfied with its quality, it may be difficult to convey this to potential downstream buyers. Thus without private knowledge of the firm, person or product, consumers have to rely on general market perceptions. They therefore become unwilling to pay a premium for quality, and suppliers in turn become unable to sell quality products. In his market for lemons, Akerlof (1970) showed that this in theory leads to the removal of the higher quality products from the market, causing a downward spiral in the quality of products in the market. The market for lemons explains many of the split incentives that are often cited as barriers to energy efficiency. A tenant is unlikely to be willing to pay a rental premium for efficiency measures whose quality cannot be ascertained. Similarly asymmetric information in developing countries is a serious problem, especially between borrower and lender. This leads to lenders requiring large returns on investment to cover the perceived risk. Developing markets, like energy efficiency, share many similarities with developing countries.

In order to avoid the problem of Akerlof's market for lemons, many institutional guarantees are offered to provide energy efficiency quality assurance. Frequently these are backed by the Government or by another organisation with appropriate credibility. Direct government intervention in New Zealand currently takes the form of information like EECA's *Energy Wise News*, and schemes such as mandatory energy performance labelling. Performance labelling schemes provide consumers with better information so that they can make a purchase decision with more confidence. Similarly eco-labelling schemes allow consumers to exhibit their preferences towards products with a lower environmental impact (Hume 2004). Energy performance contracting allows consumers to pay for the efficiency measures through the energy savings that they receive, while at the same time reducing the informational requirements and risks before making a purchase commitment.

CURRENT RESPONSES TO BARRIERS

Public intervention in the energy efficiency market typically takes the form of regulation or incentives. The majority of the policies cited in the World Alternative Energy scenario (IEA 2004) are either regulation or incentive schemes such as minimum energy performance standards, subsidies and research support. These measures are used because it is accepted that existing market mechanisms will not naturally move beyond serendipitous increases in efficiency. Indeed, in many cases intervention has proved to be highly effective. Boardman (2004) provides an example of the UK home refrigerator market, which had been the target of market transformation policies. The implementation of performance labels and minimum energy performance standards led to the average efficiency of refrigerators improving 40% between 1990 and 2004. Notwithstanding this success, and despite the potential for more gains, a planned second update to the minimum energy performance standard did not occur. Boardman (2004) concludes that the failure to implement a second minimum standard by the EU has led to "highly cost-effective savings being missed through weak policy". Thus, although regulation can be highly effective, it nevertheless relies on ongoing and sustained political endorsement to maintain its effectiveness. Incentive schemes are similarly vulnerable.

The prevailing policy focus on regulatory and incentive measures to achieve improvements in consumer energy efficiency is not well aligned with energy supply market deregulation. Arguably, 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. The primary concern with regulatory and incentive processes is that they will require continued political acceptance to be effective in the long term. By contrast, market-oriented measures like energy performance contracting and industry-initiated environmental labelling (Hume 2004) have the potential to create a robust continuing demand for consumer efficiency. These may require initial government stimulus, but have the potential to create continuing market-driven improvements in energy efficiency without the need for sustained political backing.

The results of market-based measures are less predictable than regulation and incentives but reflect the consumer preferences more directly so they are therefore unlikely to lead to deleterious effects in the market. For example, consumer information programmes are generally seen as market repair mechanisms with very low costs and virtually no negative unintended consequences (CDMAG 2003). Robinson (1991) also supports this view suggesting, " that the goal for energy efficiency policy must be to rely as far as possible, … on market mechanisms to achieve efficiency targets, supplemented as required by measures intended to improve the functioning of those mechanisms where they exist and to substitute for them where they don't".

It is relevant here to emphasise the potential contribution of improved consumer energy efficiency in achieving the central goals of energy policy—security of supply, environmental sustainability and economic efficiency. While these are often seen as conflicting, consumer efficiency induced energy savings offer an option which supports all three goals (Boot et al. 2003). The organisational and behavioural barriers described already provide substantive reasons why energy efficiency uptake is sub-optimal in the present market. Intervention through regulation and subsidies is most often used to treat market deficiencies but frequently treats the symptoms and creates a dependence on a favourable political environment. Market-based approaches on the other hand have the potential to create and sustain a consumer demand for energy efficiency, encouraging the market to address current deficiencies and prevent them from recurring, without an active dependence on continuing favourable politics.

OTHER OPTIONS

New Zealand is presently faced with parallel challenges on the supply and demand sides of the electricity security equation. On the consumer demand side, there is a reluctance to invest in energy efficiency since the individual rewards of doing so are not sufficient to overcome the perceived risks. On the generation side, there is a similar reluctance to invest in new capacity because the rewards of doing so are also not sufficient to overcome the perceived risks. Although the details of the nature of these investments are different and the sources of the perceived risk are also different, the similarity of the generation and consumption sides of the problem is important. In exploring options for a market-based approach to energy efficiency, this similarity highlights the compatibility between energy efficiency and security of supply issues.

In New Zealand the Government has responded to concerns about electricity supply security by contracting reserve generation through a new market regulator, the Electricity Commission. Reserve generation will reduce spot market volatility but effectively caps the spot market price (MED 2003). The costs of the reserve generation contract are to be recovered through a new levy on electricity consumption. Concerns about the ability for the deregulated market option to provide adequate security of supply are not restricted to New Zealand. Argentina, Chile, Colombia and Spain have made similar arrangements to ensure supply security. Capacity charge arrangements have the regulator setting a charge which is eventually paid by consumers to generators who provide the reserve generation. The drawback with these options is that they remove the incentive for the market to independently provide new investment in reserve generation. It could even provide a disincentive, and leave the responsibility for deciding quantity and thus price with the regulator (Creti & Fabra 2004).

A more market-focused option currently operates in the Pennsylvania, New Jersey and Maryland (PJM) pool in the US where explicit markets have been created for security of supply. Under this regime, capacity markets have either price or quantity fixed by regulation, so they do not allow the market to determine the optimal level of supply security. PJM requires electricity retailers to own or purchase capacity resources equal to their expected peak loads plus a reserve margin (Creti et al. 2004). Barrera & Crespo (2003) suggest that these capacity markets may not provide the right signals because of their short-term focus.

An unsolved issue is that the costs of providing and monitoring the reserve generation required for an acceptable level of security are generally not well allocated. This is specifically a concern with the current New Zealand approach and raises the question of who should carry these costs to achieve the best overall outcome. Economic efficiency would suggest that those who place new demand on the network should contribute to the cost of maintaining supply security. Similarly, since reduction of existing demand and provision of new supply both contribute to network security those who take such initiatives should share in the benefit of doing so. Arguably if these costs and benefits were allocated to the relevant contributors, it would provide a more effective and sustainable solution to New Zealand's current capacity problems and similarly smooth the transition to a more flexible energy future.

An analysis of options for allocation will be discussed in more detail in a subsequent publication. Here we briefly present one possibility in the form of a long-term decentralised market for secure electricity. In this Energy Security Market the right to draw a specific quantity of energy from the network 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. Shown schematically in Figure 3, the market would be constructed to create a greater symmetry in investment between supply and demand-side options for increasing security. The market would be based on the trading of an obligation to offer a particular level of guaranteed supply annually or longer term into the market. An additional clause of offering the level of supply to the market at or below a particular ceiling price could be included. This would address security of supply through enforcing the obligation with financial penalties. It would discourage new inefficient demand that stresses the grid and encourage equally new supply or reduced demand which relieves the stress. Such a system has the potential to offer a market-allocated level of security of supply and provide stimulus for driving demand for energy efficiency commensurate with the benefits derived by all users of the grid.

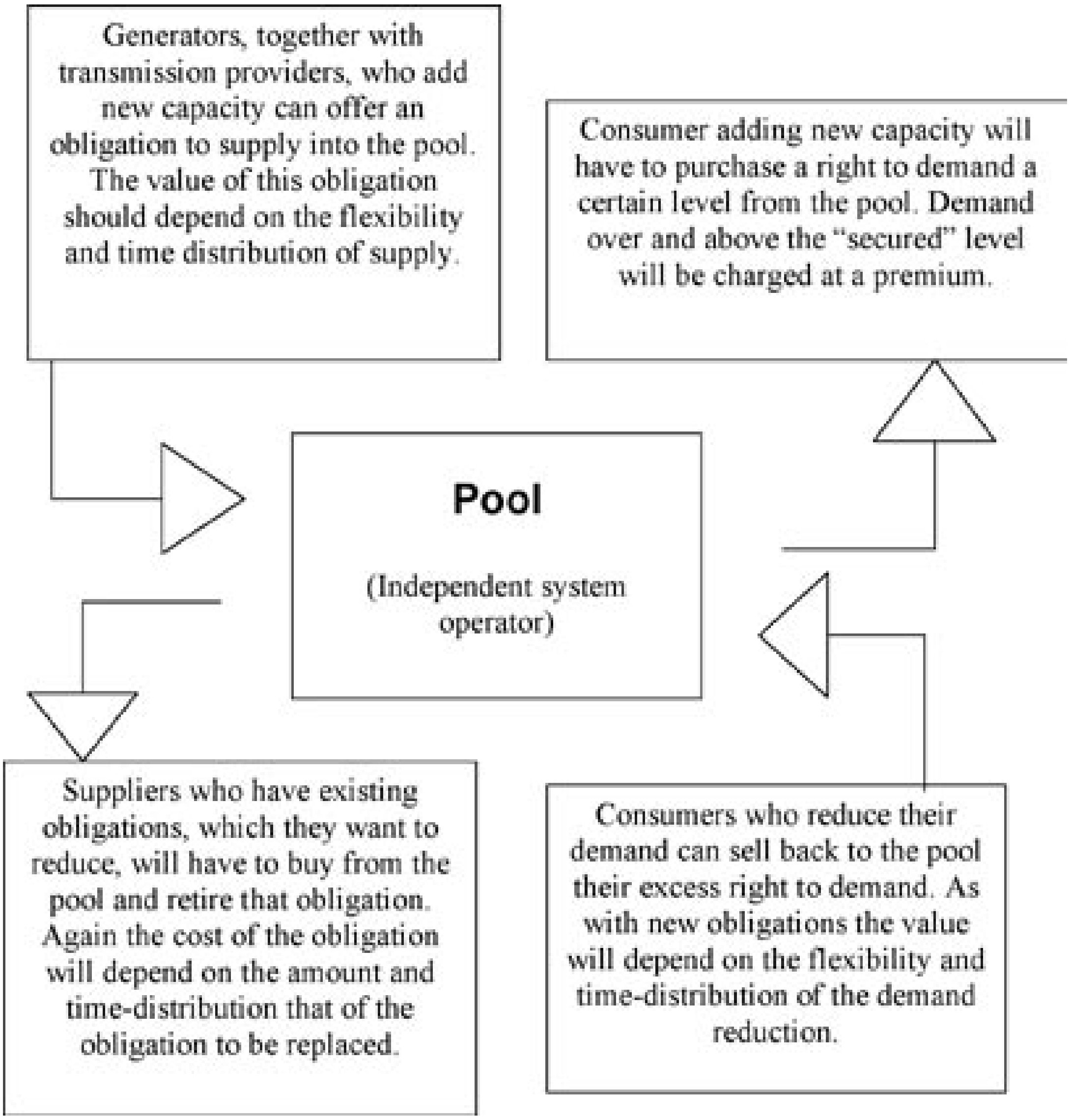

Fig. 3 Overview of an Electricity Security Market.

SUMMARY

Security of supply, environmental sustainability and economic efficiency form the basis of modern energy policy. Energy efficiency is complementary to all three (DTI 2003) yet realised levels of efficiency remain well below the most cost-effective equilibrium. The World Energy Outlook (IEA 2004) indicates that in order for the level of energy efficiency to increase, investment must shift across the meter to the demand-side. But a variety of behavioural and organisational barriers, often underpinned or exacerbated by information constraints, retard investment in efficiency. In addition, the value of energy efficiency has many benefits which, in current markets, are not allocated to the consumer improving efficiency. Presently the existence of these public good attributes of energy efficiency has motivated the Government to intervene with regulations or incentives to overcome these barriers. While there are instances of these being effective, they require sustained political acceptance. Market-based solutions which improve the alignment between investment and reward could encourage increased energy efficiency naturally but have often been overlooked.

Provision of an explicit security market could set the optimal quantity of reserves automatically and remove the need for ongoing political support and intervention. If the market were successful at providing a long-run signal for investment, it could smooth overall investment in the energy system. Furthermore it would encourage incremental approaches to investment in the electricity system, supporting distributed generation and demand-side alternatives. It would reward essentially all actions which increase the security of the system. This would link the impact of actions on system security to financial motivations, encouraging activities like diversifying the fuel mix of generators or demand reductions through increased energy efficiency by consumers. Such a market would stimulate investment in efficiency by large consumer firms, which have costs of capital similar to that of energy suppliers as opposed to the higher cost of capital of household consumers. Further it would create symmetry between the benefits received and the cost incurred when undertaking efficiency investment. However, there are many other potential consequences of such a security market. These will be discussed in detail in a subsequent publication.

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Session 2

Sources of energy

Hydrogen—a long-term future for the coal industry

Dr Rob Whitney

CRL Energy Limited

Lower Hutt

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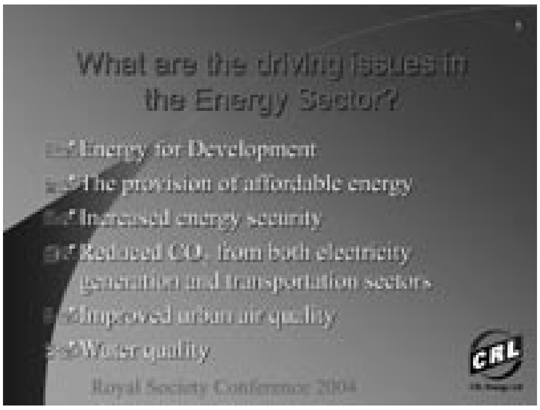

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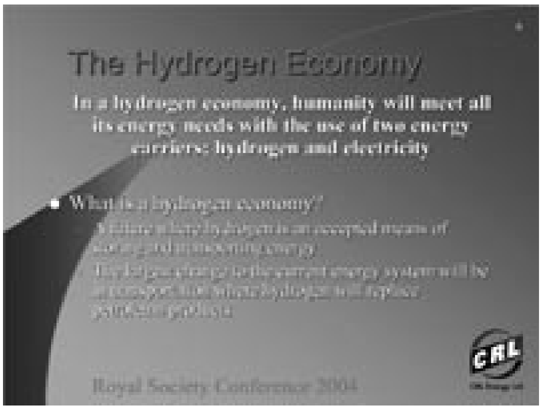

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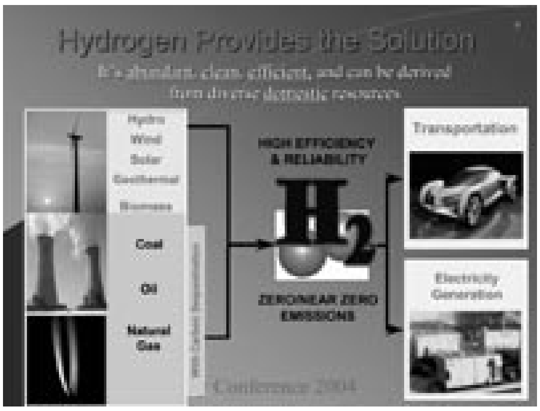

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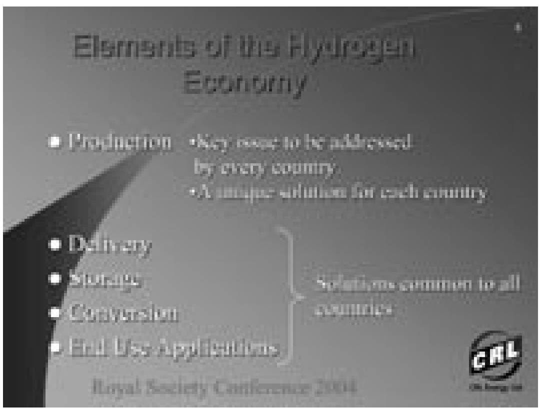

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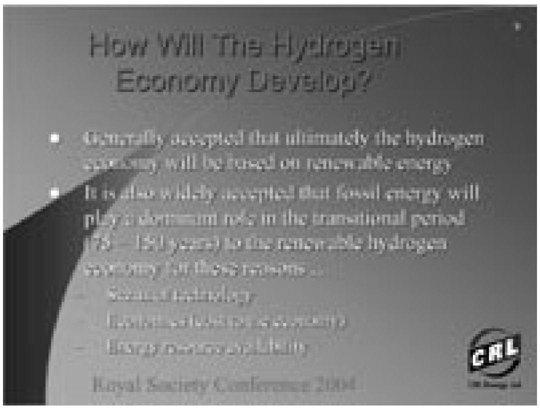

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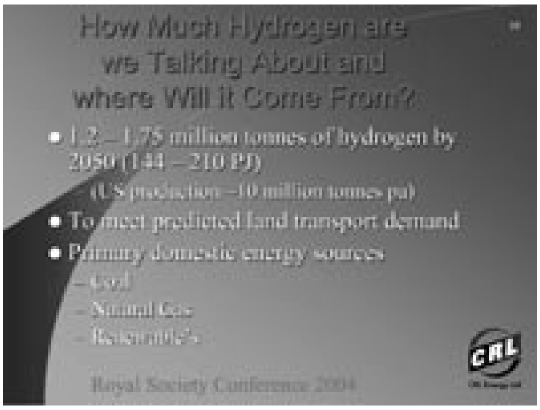

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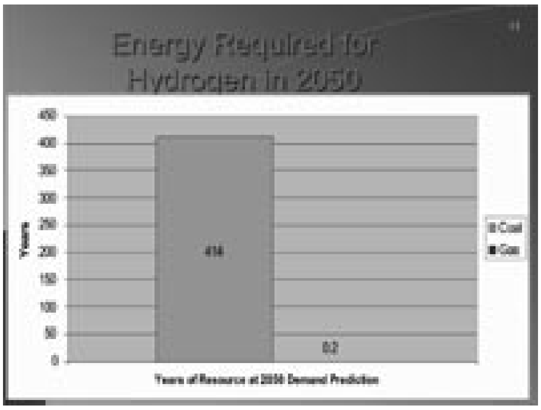

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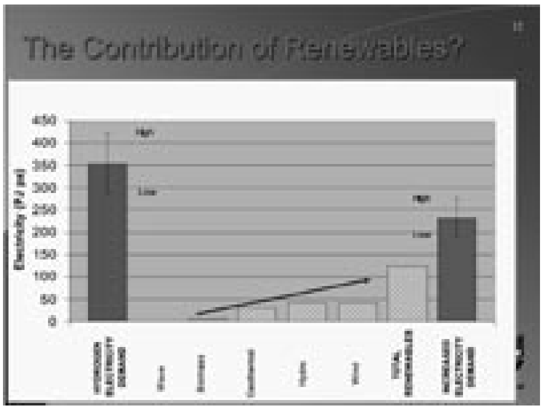

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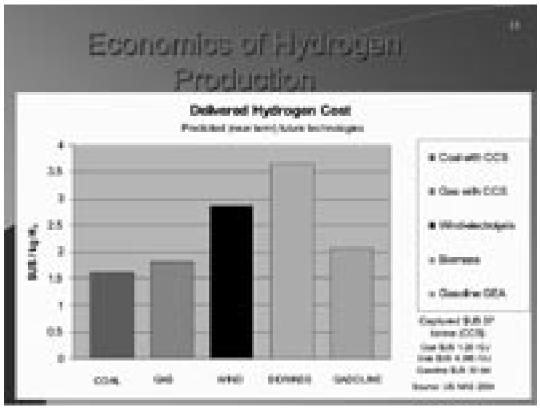

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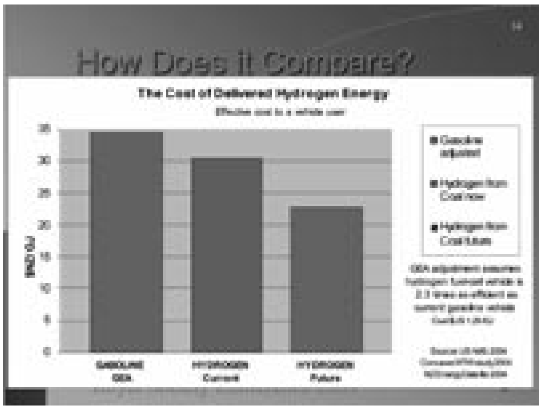

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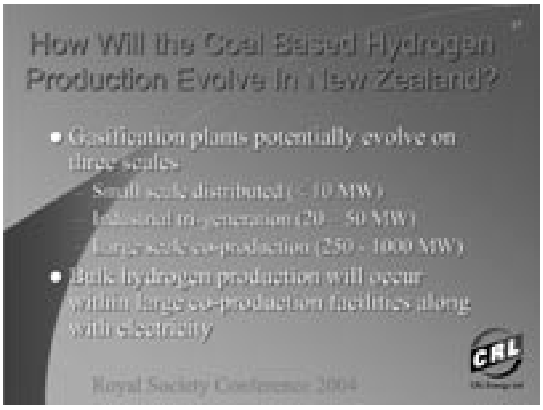

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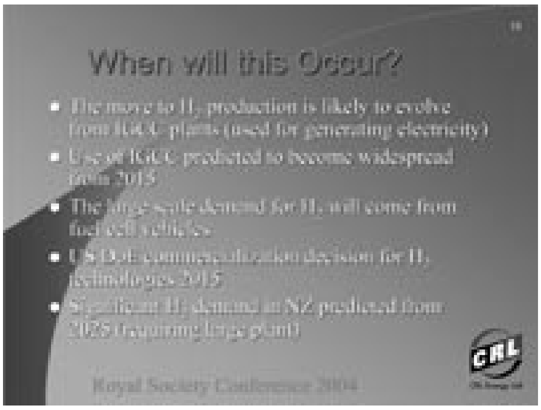

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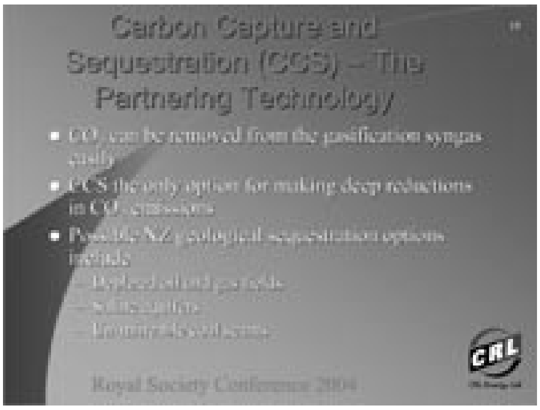

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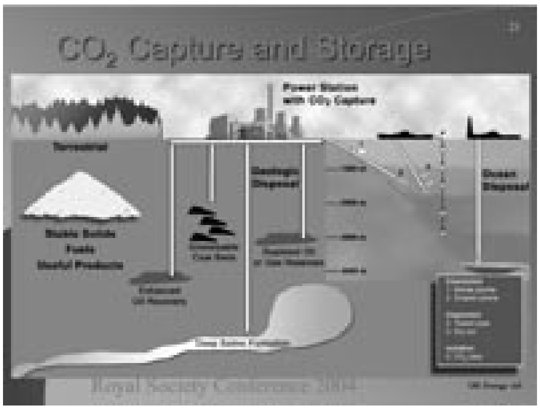

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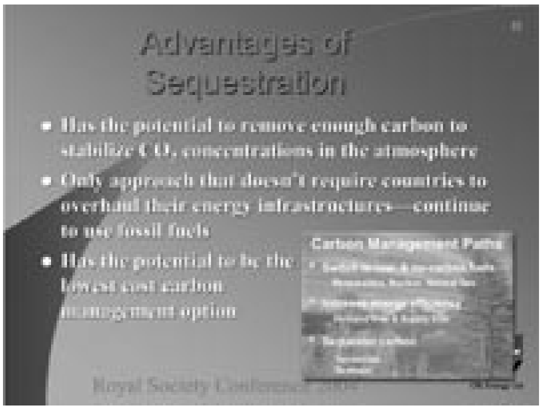

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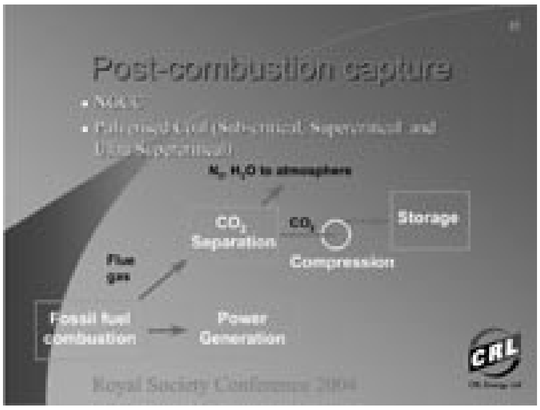

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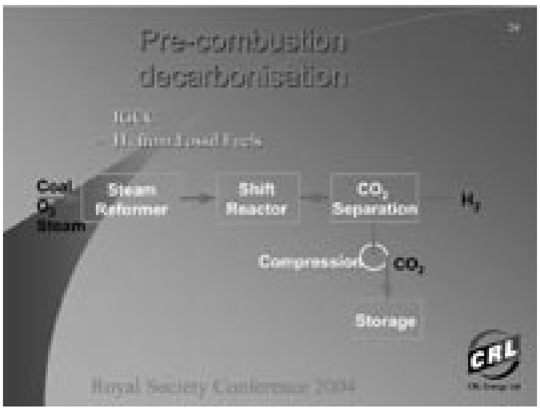

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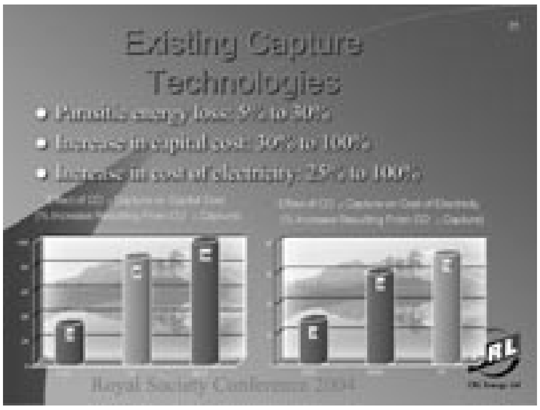

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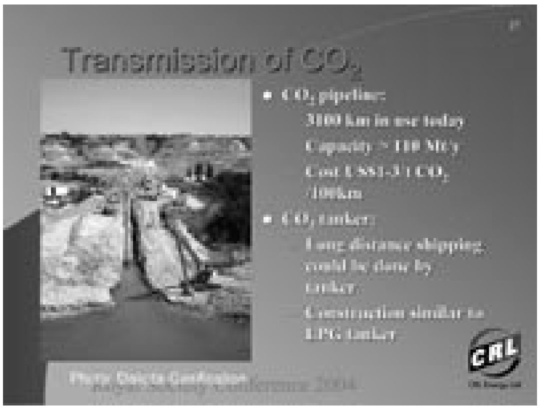

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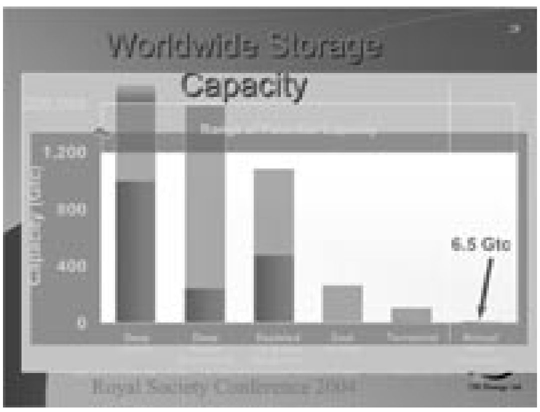

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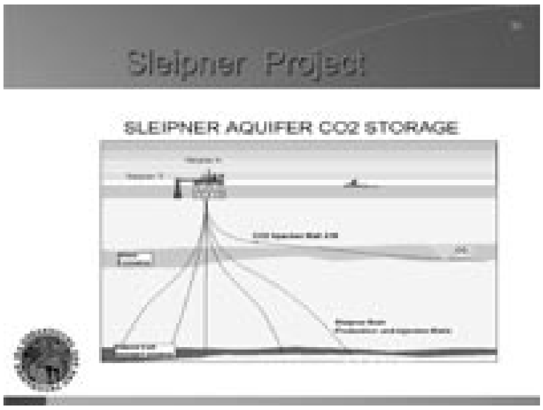

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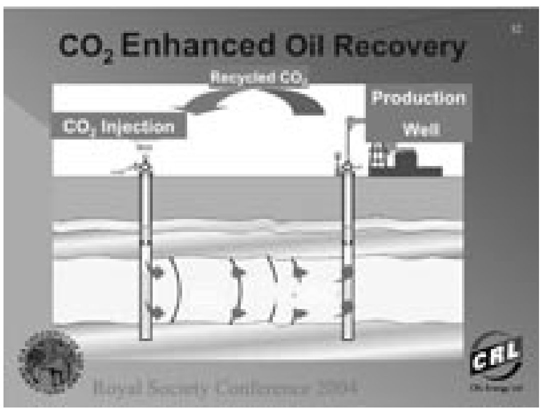

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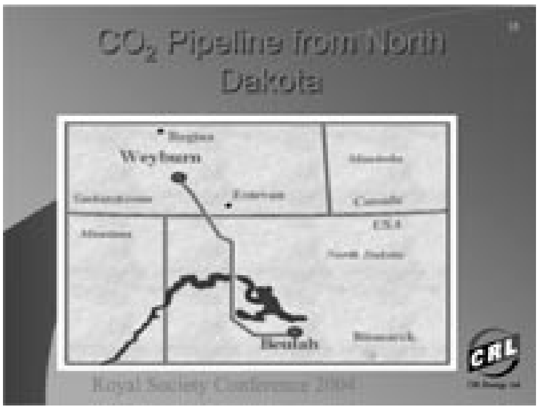

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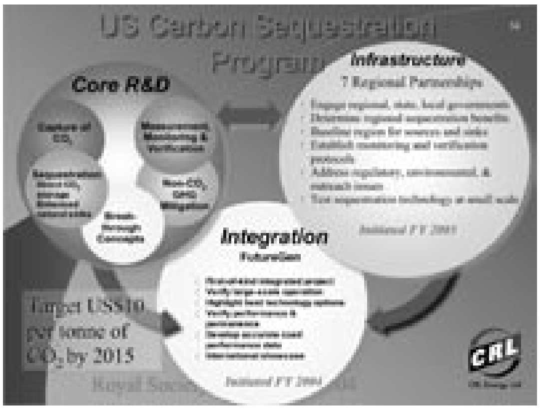

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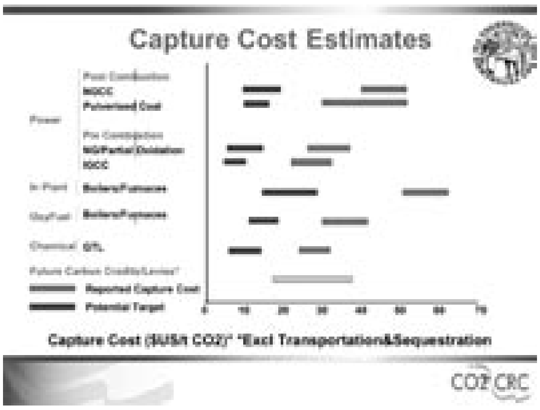

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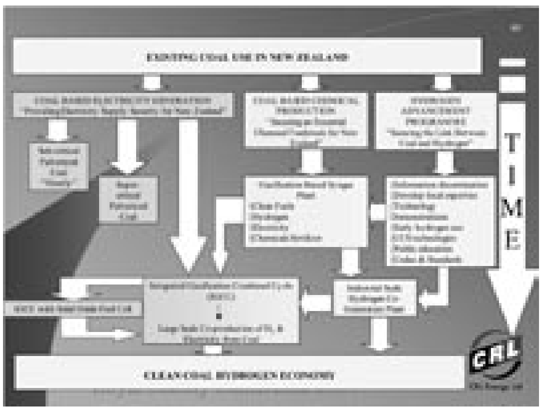

Energy gaps and how we might fill them

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Lower Hutt

ABSTRACT

Development of human society and the world economy has been accompanied by ever-increasing demand for energy. Energy consumption correlates inversely with relative poverty both through history and between nations and classes. Thus there is a strong coupling between economic and social development and the provision of energy, which is recognised as an "essential" component of a developed society. From time to time, unforeseen factors result in a "gap" in which supply cannot be made available to a component of demand. New Zealand has experienced such circumstances in the OPEC oil shocks of the 1970s, dry years constraining hydroelectric output in 1992, 2001, and 2003 and a major transmission system failure (into the Auckland CBD) in 1999. The petrochemical manufacturing sector has contracted dramatically following the downward revision in gas reserves associated with the Maui contract in early 2003. Currently perceived "energy gap" risks are 1) that New Zealand's non-transport energy market will struggle to adapt to the demise of the Maui gas field, and 2) that the global market in crude oil will be unable to function as the total global inventory of oil fields can no longer be sustained by discovery and development: a spectre referred to colloquially as "peak oil". Analysis of both of these risks requires a means to deal with uncertainty about the likely stock of undiscovered resources. Both risks have been perceived in the past and proven less imminent than feared; yet ultimately, patently finite resources must either be fully exhausted or displaced by higher-utility alternatives. New Zealand has abundant undeveloped coal resources and significant potential for undiscovered oil and gas resources. Both of these have been largely neglected for about 25 years because until 2003, the market included surplus capacity for energy production, mainly associated with the Maui gas field. In the post-Maui era, these potential solutions to the "gap" are competing with each other and with other possibilities including imported fuels and downward adjustment to demand. It is not clear how that competition should best be regulated, if at all. Government can provide greater certainty of outcome, but only at the expense of less vibrant and responsive market behaviour. Realisation of the value of mainly nationalised indigenous resources, and balance of payments, are additional policy considerations.

INTRODUCTION

Humans require energy inputs for their individual comfort and mobility and as a factor in the production of goods and services. Energy consumption in human society has grown inexorably throughout history driven by both population growth and by consumption per capita.

In large part energy demand growth has been met by the successive development of energy resources of increasing utility. These resources and enabling technologies have contributed immeasurably to human, social and economic development, and from an economic history perspective there is ample cause for optimism that technological progress will bring further gains in access to energy in the future.

Yet it is impossible to specify how and when important progress might occur. Meantime, it is quite evident that the sustainability of present-day energy systems is at risk principally from depletion of the most convenient and concentrated energy form available to us: the "fossil fuels": oil and natural gas. This possibility raises the spectre of an "energy gap".

Concern in relation to resource depletion has been variably topical during my adult life. It is manifest currently in two regards:

- globally, "peak oil";
- in New Zealand, the transition to a post-Maui era for gas and power.

From a resource inventory perspective, New Zealand is a relatively large country that is mainly comprised of only lightly explored maritime territory. What scope do the potential petroleum resources of this chunk of the planet offer for meeting our own energy demand in the post-Maui era, and even for deferring "peak oil"?

CONSUMPTION OF ENERGY

Oil company BP and the International Energy Agency publish regular analyses of global energy use, which are summarised as follows.

Annual consumption of energy in all commercially traded forms is likely to exceed the equivalent of 10 billion tonnes of oil this year, having grown at almost 3% between 2002 and 2003 (BP 2004). Per capita consumption varies considerably between countries, correlating generally with relative prosperity. Fossil fuels are the dominant source of commercial energy, and also account for almost all of the growth (Figure 1). This indicates the natural advantages of these energy sources in terms of the concentration of energy and their utility—especially in liquid form (primarily crude oil and its derivatives) which are easy to transport and can be combusted when and where required.

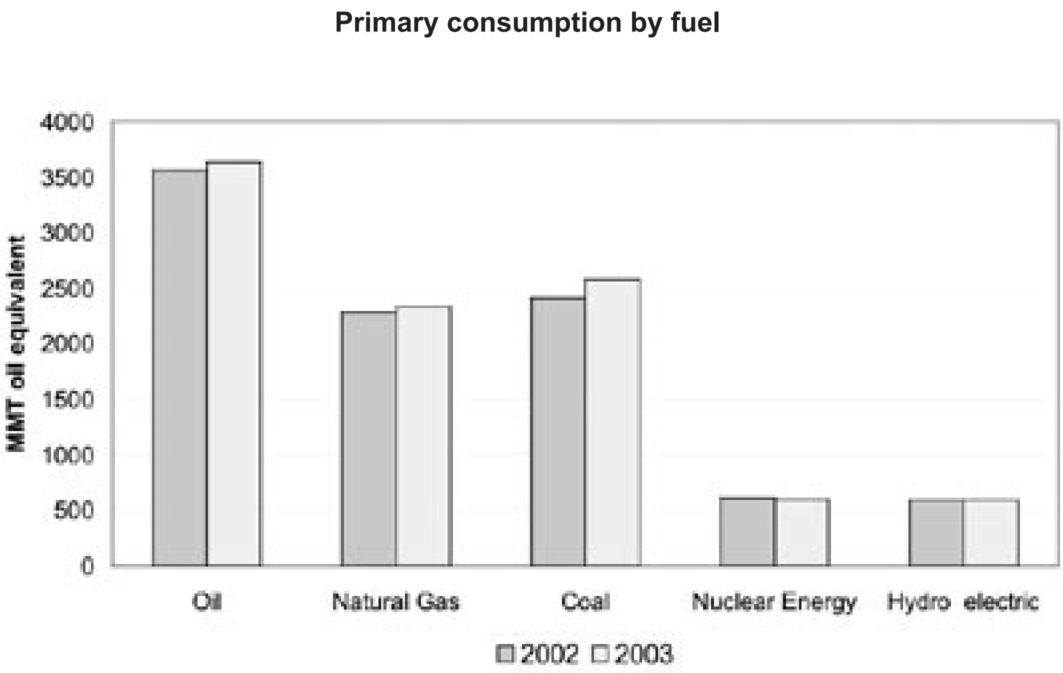

Fig. 1 Global consumption of energy by fuel type, from BP (2004). The contribution of fossil fuels is both dominant and growing.

Annual growth in energy demand seemed inexorable until the OPEC actions during the 1970s which resulted in shortages and step increases in real oil price (Figure 2). However, the global economy adapted by a combination of demand flattening and diversification away from OPEC sources, leading to falling oil prices and restored consumption growth from the late 1980s (Figure 3).

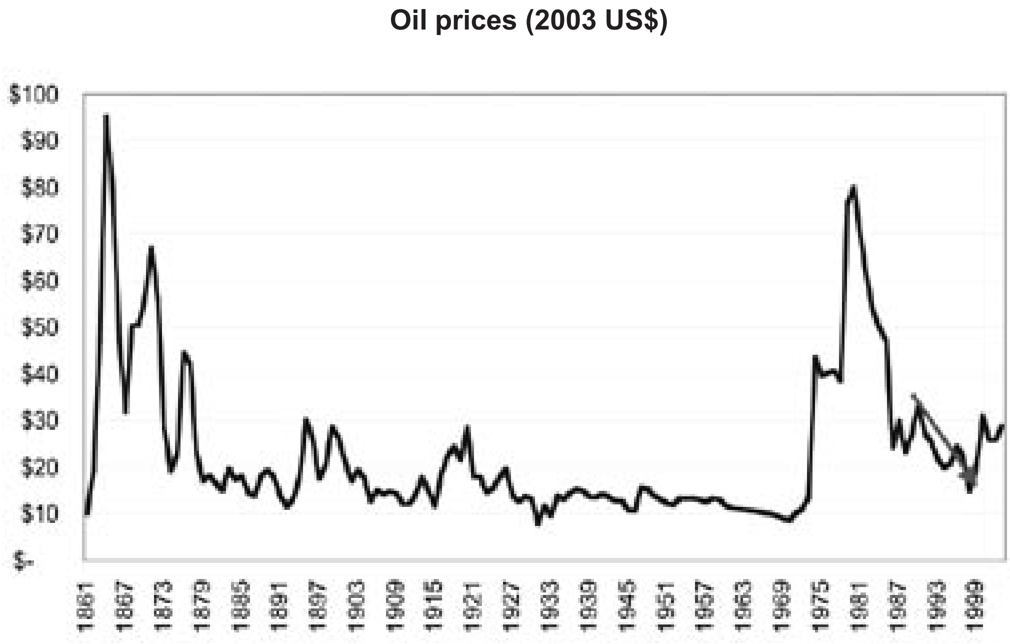

Fig. 2 Real prices for crude oil since the birth of the oil industry, from BP (2004). Arrow shows downward trend once the global economy had adjusted to the OPEC "price shocks" of the 1970s.

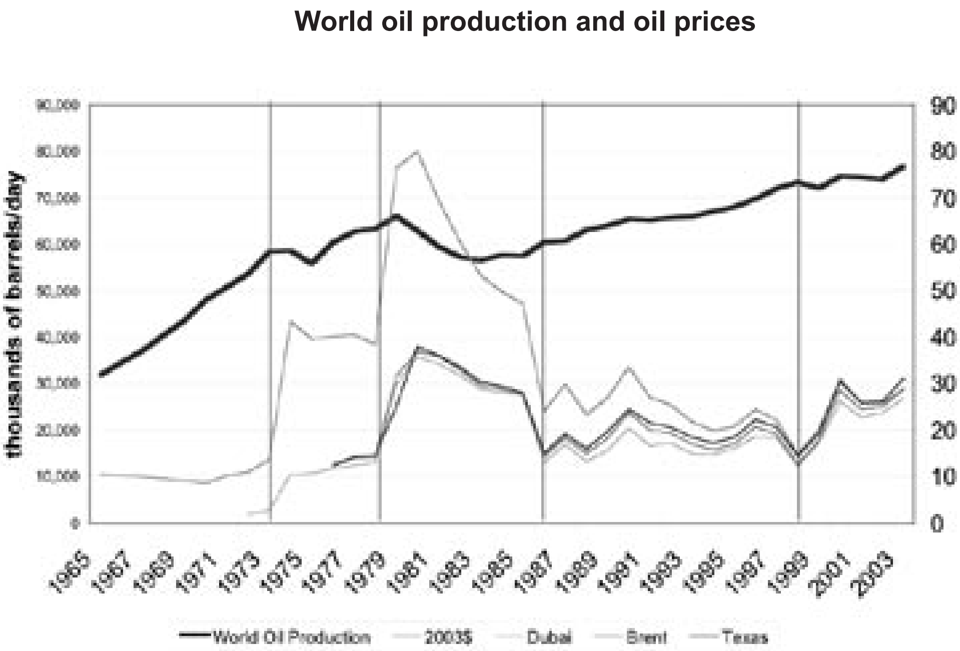

Fig. 3 (based on BP 2004) shows how demand was affected by sudden price rises before restoration of equilibrium (but with a lower growth rate) since the 1980s.

GLOBAL RESOURCES AND RESERVES INVENTORY

The fossil fuels that are so dominant in meeting the current energy demand of all modern human societies are widely recognised to be of finite quantity. Miller (1992) has estimated that the natural geological processes which operate to create crude oil achieve about 2.7 million barrels/year, whereas annual consumption has reached a level of 75 million barrels/day, so the system is clearly not sustainable indefinitely. However, as long as such a convenient and potent energy source is available at an attractive price, it seems inevitable that it will be used ahead of alternatives of lower utility. The same principles apply to natural gas, for which global consumption has been steadily rising over many years, with a significant increase in price levels from about 2000 (Figure 4).

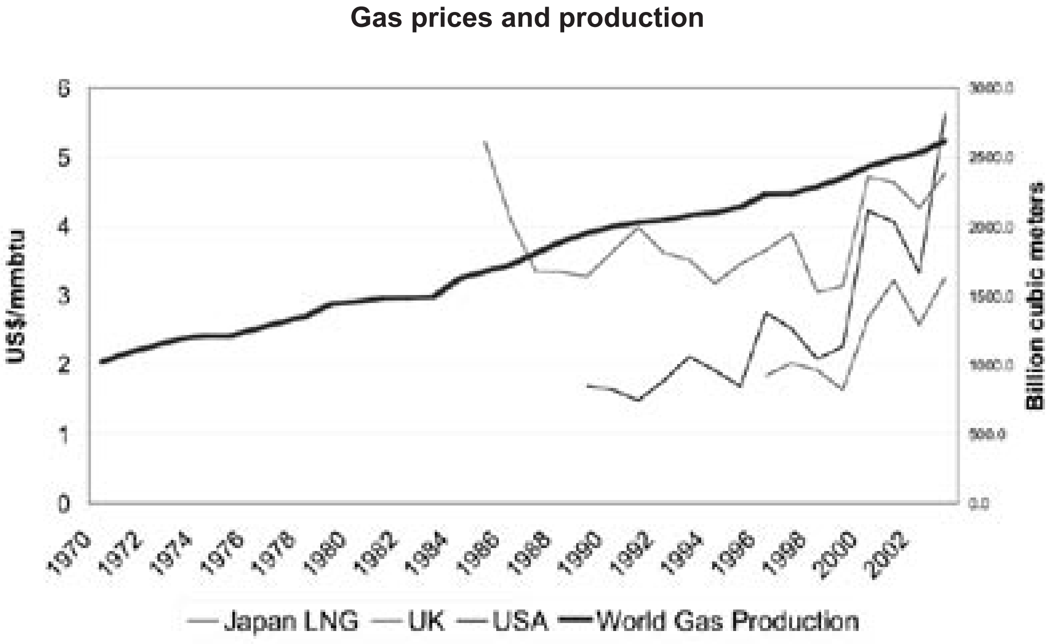

Fig. 4 (based on BP 2004). Global consumption of natural gas has grown steadily even with a significant increase in prices this decade.

While production and consumption are readily measured, the inventory from with they are drawn includes both quantified (proven and more speculative classes of "reserves") and estimated elements including both contingent and as-yet undiscovered resources (Figure 5).

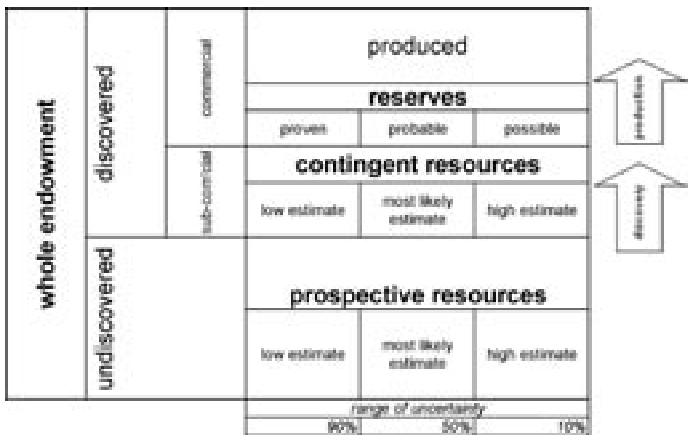

Fig. 5 Relationship between reserves and the partially un-measured total quantity of petroleum in the world. By convention, proven reserves are considered "almost certain" (or at least 90% likely to exist); probable reserves are "more likely than not", or at least 50% likely; and possible reserves are at least 10% likely

to exist. Contingent resources are inhibited by unfavourable economics, and may become reserves with changes in either price or technology. Prospective resources remain to be discovered.

It is interesting to note that notwithstanding the level of production, global proved reserves (which exclude resources already consumed) have been increasing year-on-year due to a combination of discovery, and reclassification of formerly unproven reserves due to increasing confidence resulting from appraisal, and sometimes just changes in how definitions are interpreted. Higher prices tend to bring contingent reserves, such as oil sands, which are relatively expensive to develop and produce, into proven class.

Estimates of potential undiscovered resources vary considerably, with no robust method. However it is generally held that the world's total endowment of oil, recoverable with foreseeable technology and prices, is in the range of 2 to perhaps as much as 4 trillion barrels. Since cumulative production from this base is now close to 1 trillion barrels, the concept of "peak oil" (with the potentially arguable corollary that market dynamics on the down-slope of the bell curve describing production versus year, will be dramatically different than what we have experienced on the up-slope) has become fashionable.

Fossil fuel reserves-to-production (R/P) ratios at end 2003

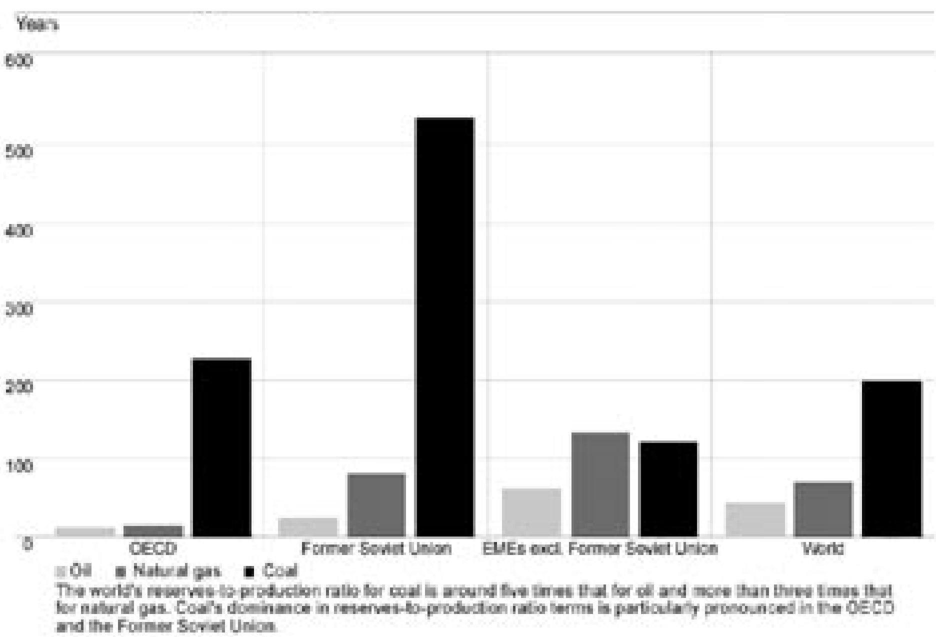

Fig. 6 (from BP 2004). Inventories of oil, natural gas and coal as a function of annual production (and consumption), by economic grouping.

Concern about "peak oil" reflects a collective or consensus uncertainty about what constitutes a comfortable inventory, expressed as the ratio of reserves to production (current annual quantity), fundamentally on the global scale. Figure 6 (from BP 2004) illustrates this ratio for the three classes of fossil fuel, by selected economic grouping, at the end of 2003. Two generalisations are evident:

1. Oil reserves are a smaller multiple of production than gas reserves which in turn are smaller than coal reserves. This reflects the tendency to draw on the resource of highest utility first, to the extent that there is supporting production capacity;
2. The more developed national economies, represented by the OECD, have lower ratios than the less developed, suggesting that prosperity correlates with greater historic efficiency in energy resource discovery and development.

ENERGY IN NEW ZEALAND

While measured within OECD, New Zealand has a number of special characteristics in relation to the place of energy in its economy. It is a relatively small consumer, by virtue of a small population, and is remote from non-indigenous sources of energy. While well-endowed with energy resources in aggregate, lack of scale has led to periodic major adjustments, and the current adaption to the depletion of a natural gas field (Maui) that has underwritten much of our energy supply for a generation may reveal much about the adaptability of a modern developed economy to the sort of predicament "peak oil" is represented as.

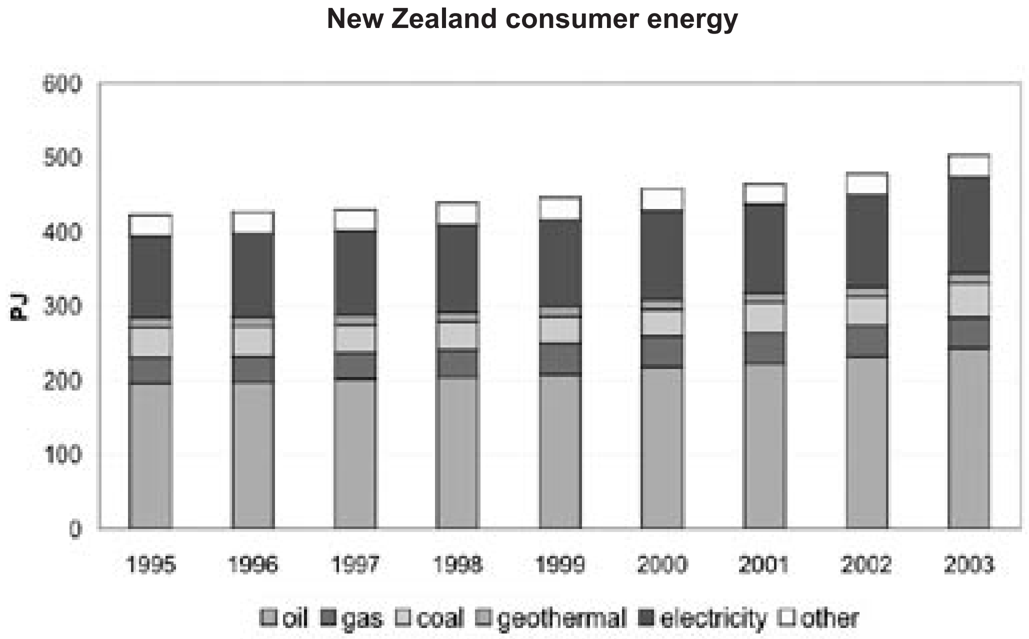

Fig. 7 Sources of the energy delivered to consumers in New Zealand. Thermal (fossil) fuels have contributed between one sixth (1995) and one third (2001) of electricity generated, in addition to the direct uses shown.

New Zealand's statistics are supplied by the Ministry of Economic Development Energy Data File (Ministry of Economic Development 2004). The relative importance of fossil fuels is somewhat lower than world average, because of the high concentration of hydroelectricity and to a lesser extent geothermal energy. However, oil-derived transport fuels together with natural gas have accounted for well over half of primary energy throughout the 30-year period of record (Figure 7). The particular significance of natural gas can be seen

1. in significantly reducing oil consumption between 1975 and the late 1980s, and coal consumption throughout the period;
2. in supporting a high growth rate in overall energy supply in the economy through the last two decades of the 20th Century.

NEW ZEALAND'S GAS RESOURCES

The present level of public interest in New Zealand's gas resources is completely unprecedented. When significant discoveries were made at Kapuni in 1959 and later at Maui, gas had no immediate economic value because there was none of the capital infrastructure required to develop the fields and connect wells via processing facilities and pipelines to potential customers. Even beyond that, there were virtually no potential customers because consumption also required investment in capital plant. As elsewhere in the world, the discovery of gas was a result of exploration for oil, and its development was a supply- rather than demand-driven opportunity.

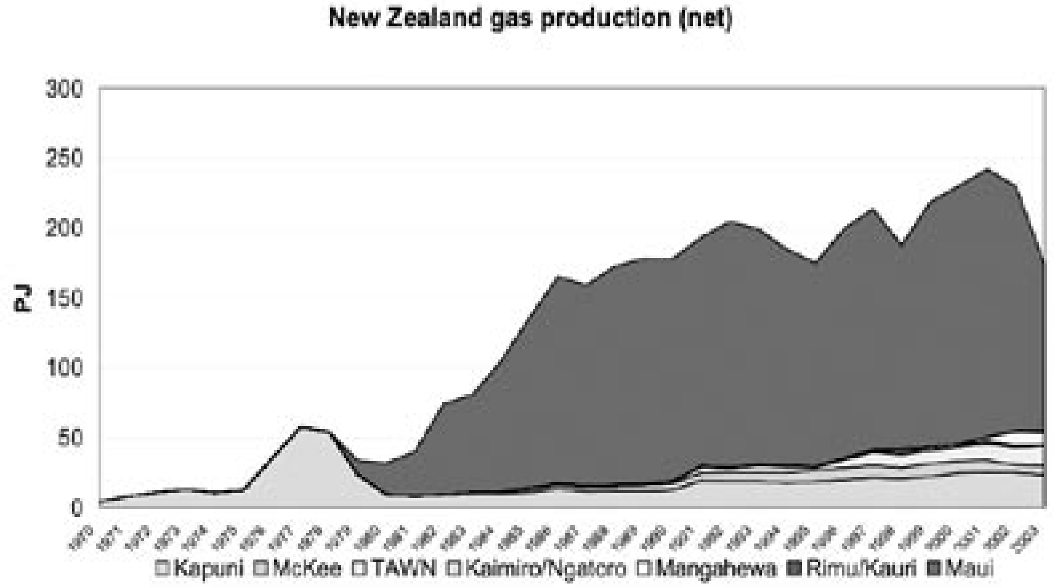

Fig. 8 Natural gas production (exclusive of losses in production, LPG extracted etc) in New Zealand since first production. Growth in the period from 1975 to 1985 reflects the "Think Big" era driven by the opportunity represented by the scale of the Maui field. 1986 to 2002 was a period of cyclical growth with high hydro-electric output depressing demand in 1995 and 1998, and the converse in 1992 and 2001. The redetermination of "economically recoverable reserves" from Maui at the beginning of 2003 introduced the post-Maui era.

The infrastructure that was created, so that these gas resources could be exploited, transformed New Zealand's energy market and its economy (Figure 8). But it took several years for demand to meet the impressive capacity of Maui and its onshore Taranaki supplements. Consequently there was no real incentive to discover or develop more. Indeed the Kupe Field, discovered in1986, has remained undeveloped for want of a market at great cost to the private interests that financed its discovery and appraisal wells and seismic surveys.

For almost 2 years now, demand in the New Zealand gas market has exceeded the capacity of developed fields, and prices have been bid up to levels that incentivise exploration for gas in its own right (discussed further below). To what extent will this call for gas be able to be met by the country's endowment?

A large inventory dis-incentivises exploration. In New Zealand context, Maui Field production capacity was for many years so large, and its contractual hold on the market so complete that there was little incentive to invest in further discovery because prospective gas sales revenue was so far in the future as to be of little value irrespective of price. The exploration that was conducted was specifically directed at oil rather than gas.

We have been able to observe the effects of increased "gap awareness" over the past 2 or three years. In Figure 9, the escalation of prices realised by producers of natural gas in New Zealand (approximations for the Maui Contract price, and rumoured Pohokura price struck in 2004, together with reported prices for Swift Energy's New Zealand production) is depicted together with previously unpublished estimates of the prices required in various New Zealand exploration theatres to commercially justify investment in the discovery and development of representative scenario resources.

It can be seen that (neglecting the considerable uncertainties in the analysis) exploration for gas onshore Taranaki became justified by prices realised during 2003 (coinciding with the downward redetermination of Maui Contract reserves). This broadly coincided with a measurable up-turn in exploration investment there, including drilling. Even stronger prices indicated for major contracts negotiated in 2004 suggest that both offshore Taranaki and "tight gas" (relatively low rate, generally deep and expensive to develop) onshore can be commercially viable. Again, the level of exploration investment with such objectives has risen sharply consistent with perception of a price signal.

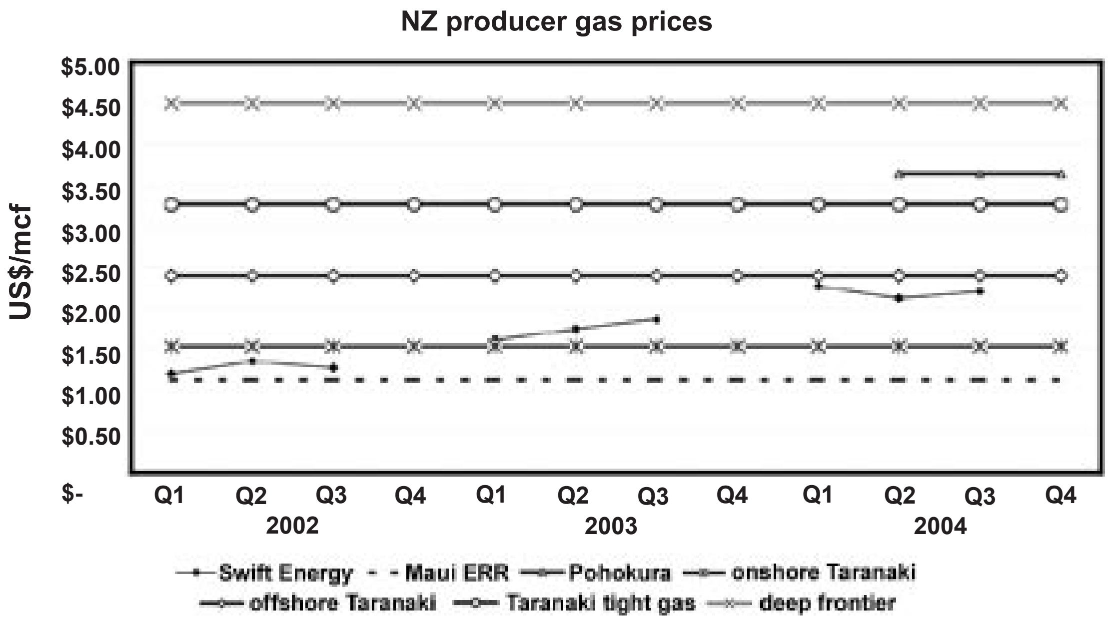

Fig. 9 Producer prices for natural gas in New Zealand, including reported quarterly averages for Swift Energy; estimates for Maui (reserves covered by pre-2004 contracts) and Pohokura (contracts agreed in 2004). Other prices are author's estimates of thresholds for a reasonable commercial return on exploration investment in four exploration theatres.

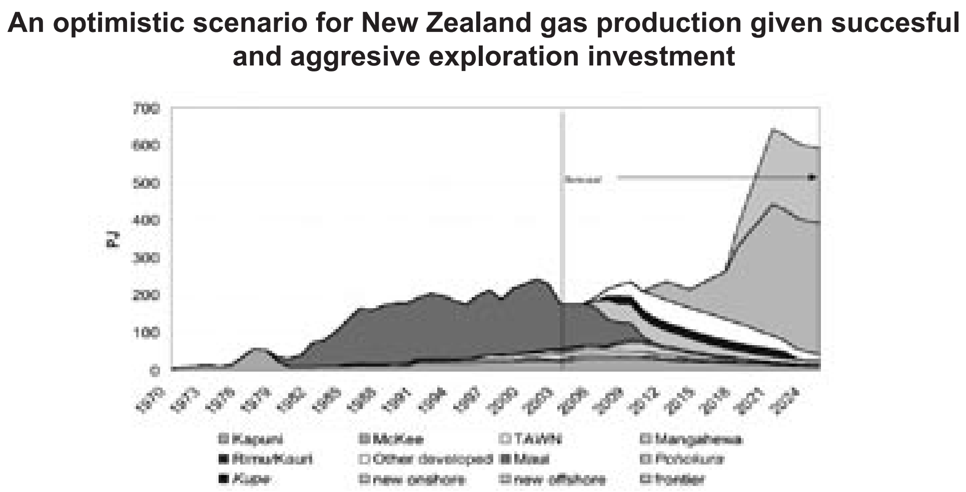

Fig. 10 New Zealand may have sufficient natural endowment of natural gas to reconstruct the scale of the Maui era domestic market, and conceivably to become an exporter as transportation technologies are developed and subject to as-yet unrealised producer prices.

The global gas market has largely developed on the back of reserves discovered as a collateral outcome of oil exploration, and until the 21st Century, natural gas producer prices have not been sufficient to commercially justify exploration in any but the most convenient markets (Figure 4). Recently prices have improved considerably and technologies for development, conversion to convenient forms, and transportation are opening up a more global market. Assuming these trends continue, then the exploration in New Zealand's considerable offshore territory will eventually become commercially attractive, and the scenario illustrated by Figure 10 (extending Figure 8) will prove plausible.

Fig. 11 Known distribution of gas hydrate off the East Coast of the North Island (courtesy Institute of Geological and Nuclear Sciences).

Beyond conventional resources, New Zealand's offshore territory (e.g., off the East Coast—Figure 11) also contains very large resources of gas hydrate, a solid phase concentrating energy but currently lacking in development and conversion technology.

DISCUSSION

New Zealand is demonstrating some important lessons about the dynamics of our energy markets in relation to long-term supply factors. The current transition from the comfort provided by the formerly ample inventory of the Maui gas field's developed and contracted reserves is occurring with little Government intervention (none of it timely). It remains to be seen to what extent rejuvenated exploration investment will restore the country's natural gas reserves inventory to a "satisfactory" level, and what oil reserves may also be discovered, from the natural endowment of unknown scale. However early indications are that since post-Maui prices have begun to be discovered, exploration investment has at least begun to respond.

It is difficult to specify what an equilibrium inventory of natural gas for the New Zealand economy is. A useful measure is the ratio of reserves to annual production (R:P). New Zealand's official figure for proven plus probable ("2P") gas reserves is 2170, giving a current R:P of about 9 over record 2001 production, or about 12.5 over 2003 production. To lengthen R:P, the market has progressively shed most, but not yet all, gas-fed petrochemical manufacturing and raised the share of coal as fuel for thermal electricity generation. Although investment in renewable energy projects (especially wind and new geothermal projects) has leapt considerably, the proportion of these sources in overall energy supply continues to diminish. Undeveloped gas reserves have been snapped up for thermal electricity and other high-value uses. The recent formal decision to construct a new gas-fired power station (Huntly e3p) required a government indemnity in respect of the risk that there may be insufficient fuel for the economic life of the plant. This may be a useful indicator of equilibrium R:P—when reserves in a market cover the full economic life of new projects dependent on consumption of that resource.

The global oil market is currently operating with R:P in the range of 50 years, and annual reserves additions have tended to exceed production for several years. Notwithstanding a wide range of important geopolitical factors, it may be that the intersection of R:P with some threshold related to economic life of consuming plant (probably in the 15-25 years range) will be the trigger for adaption to the "post-oil" era, rather than the date when 50% of the natural endowment has been consumed, as widely postulated (e.g., Deffeyes 2001).

CONCLUSION

New Zealand is well-endowed with fossil fuels, but their discovery and development has been sporadic as a result of the easily glutted scale of the insular energy market. Tight supply of natural gas will likely be short-lived because newly struck prices incentivise discovery and timely development. In the meantime, coal can be expected to secure a significantly increased role as a fuel for industry and electricity.

The world's endowment of petroleum, and that of any nation, is impossible to specify accurately. A perfect answer requires imperfectable knowledge of two domains: the future, and the interior of the earth. Oil and natural gas will be hard to displace as preferred sources of energy, for as long as they are available, because of their utility in concentrating energy that can be transformed where and when required.

New Zealand's natural gas market is in the process of adapting to shortage. It remains to be seen whether exploration will restore a sufficient reserves base to sustain the current level of production, or to restore the level attained in the peak year of 2001. However it is clear that perception of shortage has resulted in discovery of prices, sufficient to stimulate long-deferred exploration investment. The lesson would appear to be that, as long as inventories of reserves available to a particular market exceed the economic life of any new unit of consumption in that market, then conventional energy sources will be priced attractively relative to alternatives, forestalling substitution.

Acknowledgments

The analysis summarised in this paper has arisen in the course of a succession of studies conducted for a range of clients over several years, most recently a contribution to a study of thermal fuel options for New Zealand conducted by the Centre for Advanced Engineering. I am indebted to George Hooper of CAE and other participants in that study, as well as to the study sponsors and other clients for energy supply advice, for framing the important questions this paper attempts to address. I am also grateful to Alan Sherwood for his suggestions to improve the manuscript.

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Sources of energy

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Wellington

ABSTRACT

New Zealand's energy-dependent economy is very exposed to the depletion of the Maui gas field, probably around 2007. This creates immediate pressure to find new energy sources, which in turn is proving a fundamental test of the market mechanisms that took over from central planning after 1984. There are signs that a lack of faith in those mechanisms is pushing the Government into short-term interventions that may prove sub-optimal in making the most effective use of available resources over the longer term. A feature of New Zealand's energy market has been the locking out of other options for long periods, first by hydro-electricity and then by cheap gas. The paradox of achieving economies of scale in energy technologies despite our relatively small, island economy could lead to a further period of heavy reliance on just one dominant energy source, making it especially important to ensure that all options are given careful consideration as we make the transition to a post-Maui economy. There is some political support for harnessing sustainable resources through mechanical processes, but the social and environmental barriers to large-scale exploitation of wind, tidal and wave energy are adding to costs and reducing the potential contribution of these resources to the future energy balance. The Government's recent decision to effectively underwrite a further large gas-based generation plant demonstrates that, despite official support for sustainable options, and for promotion of energy efficiency, there is a recognition that further dependence on fossil fuels is the more realistic approach. Conversion of coal and lignites to electricity would appear to be the most certain post-Maui option, but administrative structures need immediate attention if orderly investment in coal-based generation is to be achieved. Especially if a significant carbon tax is imposed, the current electricity market arrangements imply across-the-board power price rises that could result in an economic slowdown and stranded investments if coal-fired generation investment occurs. Gas remains by far the most attractive future option, provided more can be discovered and developed in time to meet energy demand growth. Unfortunately, the possibility of another cheap gas discovery is a factor that other energy options with high up-front costs and long lead times must contend with. An appropriate contractual structure is required to make those other options viable in the face of this threat. Possibly the Crown, or else the wider electricity industry, is the only viable counterparty to such a contractual structure.

SOURCES OF ENERGY

From time to time we hear how New Zealand ranks near the middle of the top 100 energy-consuming nations, and that we are up at 13th in the world in per capita energy consumption (ahead of Germany, France and the UK). However, we shouldn't take ourselves too seriously: New Zealand produces and consumes a trivial amount of the world's energy—around 0.5% of the total, on a kWh basis. What's more, as well as having to carry the energy burden of shifting freight and people relatively vast distances, we—like many of the other countries identified as profligate users—put quite a lot of our primary energy into metals, wood pulp and petrochemicals manufacture for the benefit of other nations' consumption statistics.

We have some very real and immediate energy supply problems. Maui gas could be gone in a couple of years, construction of new power stations is barely keeping up with the degradation of existing ones, electricity consumption seems to be rising faster than officialdom wants to recognise and, after nearly 20 years of ongoing energy sector reform, we have run down skills and labour resources just as the economy faces the parallel challenges of reinvestment in roading, rail, electricity generation, transmission and distribution, water supply, and Maui substitution.

We also face some worrying demand trends. I'm going to focus mainly on electricity, where demand seems to be leaping ahead this year.

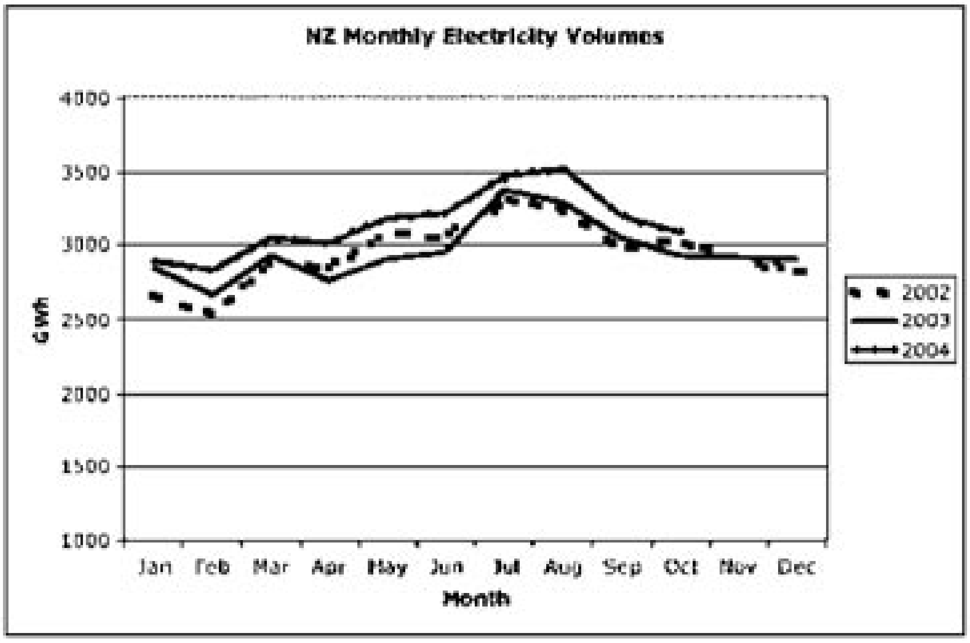
Sourcing electricity involves a marriage of science and economics, where rifts exist that neither governments nor markets bridge very well. Perhaps these gaps have just closed a bit: economists make decisions on the premise that *in the long run we'll all be dead*, and now scientists have told us that the long run is just 100 years ahead – the point when global warming will supposedly destroy us.

As in many bad marriages, one partner has dominated. We're approaching the 20th anniversary of the start of the Douglasite revolution, where central planning of electricity investment gave way to market forces, and some sort of tyranny of the economist began. I think 20 years is the china anniversary, but maybe we should think of it as 20 years of paper anniversaries—walls of paper!

It was a brave move to task market forces alone with stoking up investors to provide for our energy future. Especially in a little island economy like ours, it takes a great deal of courage to commit large sums of your own money up-front to lumpy ventures that make fairly unspectacular returns over long time periods, where events like earthquakes, economic downturns or government interventions can be expected to happen along the way.

For close to a decade it's been clear that electricity market signals, in the form of price incentives, were myopic to the point of near blindness. The market focuses very well 5 minutes or half an hour ahead, and can tell you a bit about the forthcoming 6 months, but that's all. This means that investors need to look beyond the market, at the simple patterns of supply and demand, and take a punt on prices behaving rationally when plant eventually comes on stream.

An investor with a solid grasp of economics knows that any delay in getting a return magnifies the costs and risks of any investment. Returns more than about 15 years in the future are almost worthless when they are discounted back to today. This is why the little bit of generation investment that has occurred, and is about to occur, is overwhelmingly gas-fired, despite the fact that this will create big problems for the economy if the gas dries up. Gas-fired plant has a low up-front cost, and can be built and brought on stream fast. It dovetails neatly with the economist's view of the long run: up-front returns, and *who gives a damn about 10 years ahead?*



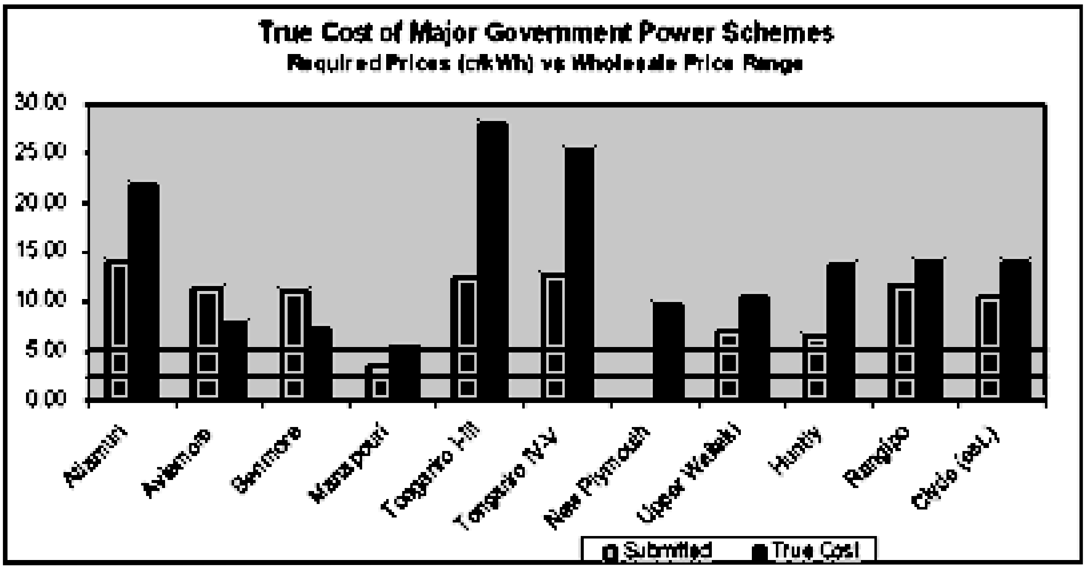
Source: EMS Reconciliation Manager October 2004

Making our power-sourcing decisions on the basis of commercial perspectives of supply and demand trends is another challenge, especially given the dubious statistics we have. However, it is a challenge someone needs to respond to, and fast. In 2002 and 2003, as in most other years, power demand was up some months and down in others. Since December 2003 it has been significantly up on past years every month, a trend we have only experienced during the Think Big demand build-up of the 1980s, and before that during the boom years of the early 1970s.

The electricity system might just scrape through a dry year event in 2006 if we keep on having annual demand growth around the Ministry of Economic Development's forecast range of up to 2.5%. Just one year of 5%-plus demand growth could leave us seriously exposed.

It is illuminating to reflect on how we have let ourselves get into this situation, and in particular on what it might mean for tomorrow's sources of energy.

Back in 1983 a scientist, the late Dr Corrie McLachlan, was seconded from the then DSIR to the Treasury to help with number crunching. His major achievement there was a study of *The True Costs of Electricity Generation* that may well have launched the Douglasite revolution. Basically, it said that the Government was a hopeless investor and an even worse price setter. Power stations built since the 1940s needed (in today's terms) somewhere around 15 cents/kWh to be commercially viable, and were recovering less than 5 cents.



This revelation came just ahead of the collapse of oil prices that left Think Big high and dry, and various other revelations about the failings of planned economies. The answer was to get the Government out of investment in the energy sector by privatising anything that could be privatised, and creating quasi-private sector drivers for what was left by transferring control from departments to State-owned enterprises.

We will never know if the Douglasites got it right because we saw very little new private investment in the energy sector. A lot of money was spent on buying existing assets, and a lot of money was made by shedding trainees and R & D programmes, lowering security margins, borrowing against revalued asset bases, and scrapping stand-by plant. Just as the wholesale electricity market at last seemed to be working it was neutralised by a Government edict forcing power buyers to sell their businesses to power generators, destroying the buyer/seller tensions that make markets work.

ARE GOVERNMENTS GETTING THINGS RIGHT NOW?

According to various official pronouncements over the past 4–5 years, tomorrow's sources of energy with come from a *rainbow economy*, with a host of small-scale, varied investments in distributed generation, sustainable energy, and energy efficiency delivering an annual trickle of new supply that will steadily displace old plant and meet tomorrow's demand growth. This will be propped up by significant new gas discoveries, while the Victorian evils of big plants, coal and tall chimneys will be chased off to Asia by a carbon tax that is just over the horizon.

Paradoxically, we're also now seeing a couple of major state-owned energy providers—Solid

Energy and Genesis—suggesting that coal-fired generation and large-scale Liquified Natural Gas (LNG) imports, respectively, are the most viable options open to us, and warning that time is running out if we are to avoid serious post-Maui trauma. This comes shortly after the secretive Government announcement that it has propped up Genesis' planned 360 MW gas-fired e3p generation investment by underwriting the gas supply risk in some way or other.

This difference between what the Government tells us officially, and what its actions—and those of its supposedly more commercially aware agents—say is pretty unsatisfactory for a country that's 13th in the world in per capita energy dependency.

The e3p decision looks like either political wheeler dealing or, more probably, a quick fix to make sure there is power available in 2007. If it is the latter, and we are reduced to building another gas-fired station on a site where the RMA can't delay things, despite the uncertainties about gas supply, then the implication is that the Government knows things are getting pretty desperate and that its rainbow energy economy won't deliver the promised pot of gold.

The fundamental problem is that our odd mix of interventions, faith in markets delivering, and rules and regulations aimed at promoting micro-investments, is delivering hopelessly confusing signals to investors at all levels of the energy sector. When you focus down to the individual energy supply options that could be viable in New Zealand then that confusion degenerates into chaos.

A LOOK AT THE OPTIONS

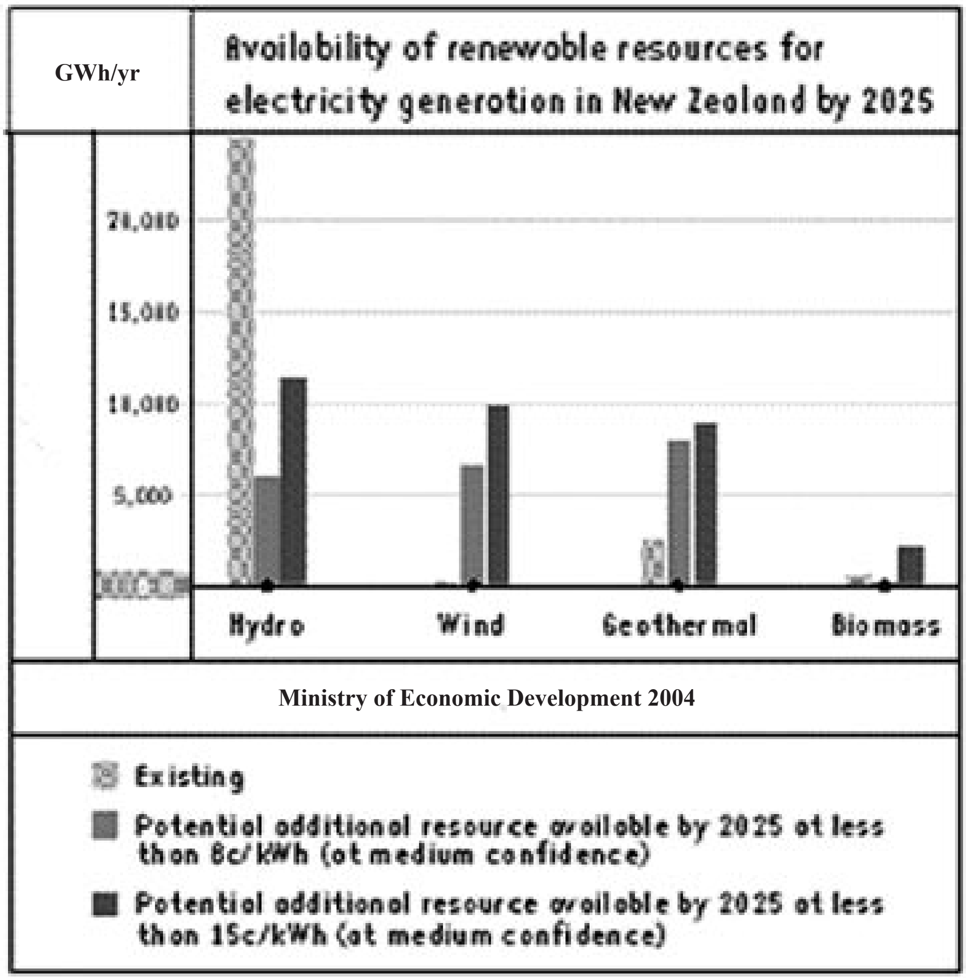
The big, largely untapped energy resources for New Zealand are coal and lignites, wave power, and wind. They are followed by whatever is left of our hydro and geothermal resources, some biomass, and not much else unless we accept nuclear options or are prepared to gamble on gas or wait for the hydrogen economy.

I won't say much about gas, because who knows whether or not we will find much more. There's a good chance we will but I wouldn't put any money into a company set up on the basis of that gamble, and nor will at least one State-owned generator—as demonstrated by Genesis' demand that the Crown underwrite its gas risk for e3p. I am also not going to get into micro technologies such as household heat & power systems, fuel cells and so forth. That's not because I feel dismissive about them but because I have only got limited time.

Looking just at electricity, if you accept the official vision of renewables playing a big part, then the Ministry of Economic Development believes that geothermal and wind, with maybe a bit of hydro (that may or may not need legislative change to let it happen) could contribute about the equivalent of the current hydroelectricity system by 2025. This is about the additional supply we will need by then, at the official 2.5% annual growth rate.

Note that wave and tidal power doesn't feature in the MED review, despite the huge resources around our coastline, which is the world's 4th longest. This could be a prudent omission given the state of the technology, or possibly given the state of our seabed and foreshore regime. However, the technological challenges for tapping some of the huge quantities of mechanical energy available from the ocean are probably less than those faced by New Zealand's geothermal pioneers in the 1950s. As a yardstick, there are estimates floating around that 1% of the energy in ocean waves is equivalent to 50 times world-wide energy consumption.

Even if we ignore the rigidities that may have been created by recent Seabed and Foreshore developments, just imagine the environmental obstacles to significant wave-harnessing installations along our coast. There is potential to disrupt valuable fisheries resources, to disturb sensitive ecosystems, and to present spiritual and aesthetic affronts to various groups. I suspect that it would be easier to resurrect Project Aqua than to tap equivalent ocean resources, at least given current sensitivities.



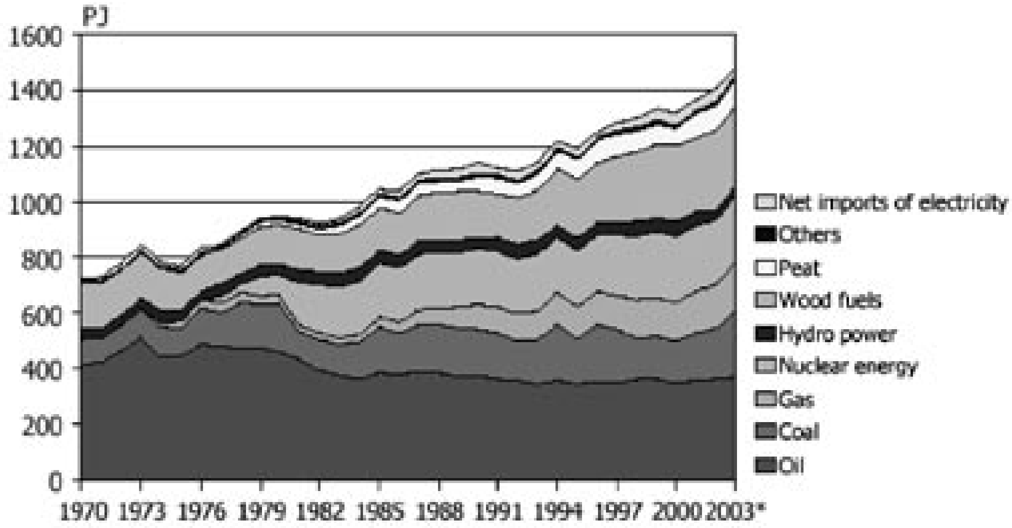
Islay 0.5 MW wave power station. About 1 windmill equiv.

Biomass looks surprisingly insignificant in the MED's chart. However, the ground water shortages being experienced around Christchurch at present are a pointer to the limits that biomass is facing. Growing things to burn in power stations diverts land and water from other productive activities. Work has been done by Forest Research and others on the marginal economics of moving low density forest waste to power stations, and it is fairly clear that any ventures seeking to extract energy from mountains of bark and sawdust generated by new forest processing ventures will face quite a few problems. What's more, the energy needs of those new pulp mills or paper mills will add to our net energy dependence.

Nevertheless, other countries seem to be able to do things with biomass, and New Zealand is producing an ever-increasing volume of wood, in a fairly saturated global market. It is interesting to look at Finland when you are considering biomass. The Finns have a big forest processing industry, and burn large quantities of biomass. Finland is also interesting from the perspective of seeing the various energy options open to a small country. With 5.2 million people Finland is about 30% bigger than New Zealand, with a similar high level of export dependence, and climatic problems that handicap it in much the same way that distance handicaps us.

Somehow Finland has also found the economies of scale to have nuclear power, possibly because they are way ahead of us in electricity consumption (they consumed 71,000 GWh in 2001, compared with our consumption of 35,000 GWh that year).

Finland: Sources of Energy



Source: Statistics Finland

The Finns don't seem too concerned about the quantities of energy they consume: not just nearly double our electricity volumes but a massive 1500 PJ of gross energy, versus our 800 PJ. Their energy prices are about a third higher than ours but, even so, biomass is the dominant renewable energy source in Finland and the other renewables don't seem to have found a niche. Perhaps because their biomass utilisation record is so good no-one seems particularly worried about the trivial role of other renewables, or about the rate at which Finland's energy, and particularly electricity, consumption is growing.

Despite our much cleaner, greener energy economy, with its current emphasis on hydro, gas and geothermal options, and despite our much lower energy consumption, we differ from the Finns in believing that we can keep our comparative advantage as a trading nation while suppressing most of the options that Finland relies on.

Moving on to geothermal power, we can be confident that very few countries will have a better record than us. Yes, we could well have about two-thirds of the geothermal resource still to be tapped, but you just need to talk to Top Energy about some of the problems they have had trying to expand their modest plant at Ngawha to know how many barriers the Resource Management Act (RMA), and the energy market, create for geothermal options.

The old Wairakei power plant has been a solid, reliable performer but, like the neighbouring Ohaaki plant, it has been suffering from falling output. While we have had three other geothermal plants commissioned since 1997, the fall-off in capacity at the older plant means geothermal output has now slipped back to 1998 levels. There is certainly a possibility that new geothermal capacity will play a big role over the next 20 years but its recent track record has been patchy. One of the biggest hurdles it faces is its limited flexibility. Geothermal fields and plant don't respond well to changes in output; they are at their best held at constant levels which means they can't crank up production at times of peak prices. The New Zealand electricity market, on the other hand, offers bigger rewards to generators who can come on stream at peak times and turn off at night or when power is plentiful. Maybe this is another area for reform.

Wind power is certainly coming over the commercial horizon in New Zealand, thanks partly to our high sustained wind speeds. Our first two commercial wind farms were built back when the dream of allowing the Government to escape from investing in power schemes was still alive. In this sense it is disappointing to now see two State-owned enterprises leading the way with the country's three major wind developments, although its encouraging to see some other parties also looking hard at wind options.

Whether wind gets very far here will depend heavily on things that could be fixed by government edict. The RMA creates up-front costs and delays in some places that seem oddly in contrast with the clean, green image that the Government's official pronouncements on wind portray. However, some of the biggest barriers are structural ones, locked up in the complex rules and regulations now mainly administered by the Electricity Commission. These barriers apply to most other forms of distributed generation also. I will mention just a few:

- The current transmission pricing arrangements. These mean that remote generators (mainly the Government's Meridian assets in the South Island) pay virtually nothing to have their energy moved to the main markets, principally in the North Island, where they compete with local wind options.
- The unique nodal pricing system operating in the New Zealand electricity market, where local prices at some 240 "nodes" around the country vary according to marginal energy losses involved in getting electricity to those nodes. Just a little bit of local generation is enough to eliminate most of those losses, meaning that the nodal price drops, and the local generator that has caused that price drop is unable to capture any commensurate price margin.
- The fixation on recovering the sunk costs of transmission through charges that do not recognise stranded assets or intermittent line use. This makes some sense, but not a lot. Essentially it misses the point that net national benefit is more important than economic rent allocation. It contrasts oddly with the arguments that we hear propounded for free trade, where this type of protectionism is seen as a sub-economic approach. If a factory goes bankrupt in Levin because of cheaper imports from China, that's its bad luck but the economy's net gain.

There is another significant barrier to wind, in the form of a prohibition on lines companies selling energy hedges. This lingers on despite successive reforms of the ban on lines companies (who are potentially significant local investors in wind power) generating from renewables. Fairly obviously, anyone generating from wind will have trouble selling direct to end users unless they are also able to provide cover, i.e. a financial or physical hedging arrangement for times when the wind isn't blowing. As long as the Government maintains this ban it locks the lines industry out of the wind market, unless exceptional circumstances allow a particular company to on-sell profitably to one of the established generator/retailers that it should be competing with.

The interest some big companies are now showing in imported LNG shows up more of the structural weaknesses in the electricity market. The most obvious one is the situation we would find ourselves in, importing Australian LNG to the North Island to make into electricity, and Australian bauxite to the South Island to convert to aluminium, and then exporting the resultant aluminium on the basis of some supposed electricity pricing advantage that made all this possible. Common sense would suggest that it would be much cheaper to pay Comalco to phase down its output. However, these types of market failures are left to the politicians, and politics isn't necessarily based on common sense.

Another structural weakness is the belief I have already referred to that Transpower should be allowed to recover its sunk costs but that other participants in the electricity market should not. If the Government were consistent, and provided it accepted that LNG imports were our best option, it would have to create, presumably through the Electricity Commission, arrangements that would protect whoever invested in the necessary infrastructure from a sudden asset stranding (which could be caused by a local gas discovery). Without this sort of protection, it is hard to see how anyone would invest in the infrastructure and probable long-term supply contracts needed to bring LNG to New Zealand, at least without a very big pricing premium to cover this exposure.

New hydro-electricity developments with an annual output of 6,000–12,000 GWh appear on the MED's list of available renewable options. Project Aqua would have produced about 3,000 GWh, and was the dominant contributor to the 8,650 GWh of production identified earlier this year in the *Economic Impact Report on Aqua* published by the Ministry. Presumably it is still featuring in the official list of renewables.

The problems Project Aqua faced, even with a massive PR programme and the deep pockets of an SOE behind it, show just how hard it is to make another large-scale hydro venture work in our environment. The huge cost over-runs in earlier hydro projects should also be kept in mind: estimating true costs in our faulted and earthquake-prone river valleys can involve a great deal of wishful thinking.

MED's list of current options.

Electricity Supply Options	Location	MW	GWh pa
Manapouri Turbine Re-runnering	Lower SI	16	75
Various Small Scale Hydro 1	Distributed	8	36
SI Hydro Efficiency Projects	SI	20	51
NI Hydro Enhancements	NI	20	100
Project Aqua	Central SI	524	3,000
Various Small Scale Hydro 2	Distributed	52	255
Wairau Hydro Scheme	Upper SI	100	526
Various Small Scale Hydro 3	Distributed	50	235
SI Hydro Efficiency Projects	SI	30	121
Various Small Scale Hydro 4	Distributed	98	426
Luggate / Queensberry	Lower SI	228	1,186
Large Scale NI Developments 1	NI	250	1,100
Various Small Scale Hydro 5	Distributed	83	369
Large Scale NI Developments 2	NI	500	1,000
Various Small Scale Hydro 6	Distributed	39	169

This brings me to *energy efficiency*.

There is no doubt that the fundamental problem facing energy supply in New Zealand is demand growth. If the economy stood still then we could probably make the adjustment from Maui to other energy forms just with renewables and an accelerated gas exploration programme. Possibly the departure of cheap gas will trigger this type of economic stasis, although past trends suggest that there would be a catch-up after a few years, and we would be in much the same supply/demand bind. The challenge for proponents of energy efficiency is to maintain economic growth while restraining energy demand.

Unfortunately our propensity to consume more rather than less is largely unchallenged. The Energy Efficiency and Conservation Authority (EECA) does its best, and the Electricity Commission is now about to prime the energy efficiency pump with levy-funded cash injections. Nevertheless, you just need to walk through the Warehouse to see how accessible bigger TVs and additional appliances have become, or to look at the endless embellishments to cell phones, computers and electronic games to appreciate how easy it is to feed our energy addiction.

A small but creditable research effort goes into energy efficiency. There are always programmes going on to devise zero energy houses, or to reduce lighting and space heating loads without impairing lifestyles. I haven't noticed this doing much good to demand figures but the political drivers to do it are getting stronger and, eventually, we might begin to pump in the sort of sums that can be squandered in doing preliminary work for abortive power schemes. It is an intriguing frontier, where the potential to defer capital costs for very little cost must exist, but is usually just out of reach.

Coal and lignites remain by far our mainstream potential energy source, and you have already been told quite a lot about what might be done with gasification of Southland lignites. Solid Energy's new *Energy Options* report highlights just how cheap these fuels may be, how plentiful they are, and how limited the alternatives look. Getting these messages across while keeping within the politically correct constraints on SOEs is a remarkable effort in its own right. It is very hard to understand how so much Government effort and rhetoric can go into promoting low CO_2 options if Solid Energy's messages are realistic ones. Presumably the Government believes that the chances of finding more gas are good enough to justify the risks of ignoring coal, and the costs of more expensive gas versus coal (or maybe, in a worst case, LNG) are bearable.

This is a big gamble, with our lifestyle at stake, and it is based on assumptions that contrast markedly with past ones. I will therefore conclude by returning to that pre-reform era of the 1980s I opened this talk with. Specifically, I'll return to the 1984 Government *Energy Plan*, the last real version of those documents, which looked ahead 20 years to this year, 2004.

Total consumer energy demand was forecast to be 460 PJ this year, which was a bit conservative—it reached 500 PJ last year (bear in mind this is up from a base of 300 PJ in 1984). Total electricity generation was forecast to reach between 34,000 and 44,000 GWh and it looks as though it will be just slightly less than that higher growth estimate, or slightly more if you account for different treatment of distributed generation.

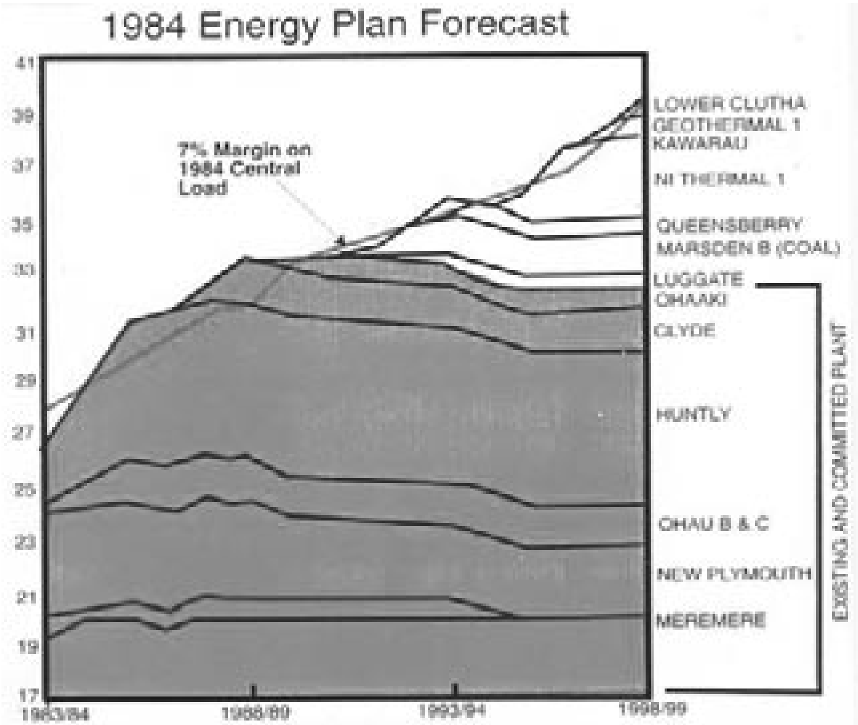
The biggest differences occur in the predictions about energy sources for power generation. To meet a central load forecast of 350,000 GWh in 2004, plus a 7% margin to account for demand vagaries and delays—a concept that seems to have been lost sight of—the following additional capacity was required to be up and running by about 1999:

The big chunk of capacity identified as North Island Thermal No 1 more-or-less equates to the new gas-fired plant that's gone in, while the original 1984 plan for the conversion of Marsden B to coal would equate to the planned e3p gas development, plus some bits and pieces.

Assembling a list of new capacity options that matches projected base load demand wouldn't seem to be too prone to error. You might get the options wrong (they did), but the actual capacity required just involves simple addition. However, we have seen demand growth significantly above the 1984 Plan, the New Plymouth station pushed into a pretty marginal topping role by transmission constraints, geothermal being debased unexpectedly, and various hydro options just not happening.

Paradoxically, the 1984 Plan envisaged Huntly converting largely to coal from about 1990 (despite an expectation that there was 25% more gas in Maui than there now seems to be). What's more, it envisaged substantial new coal-fired capacity coming on stream despite an expectation back then that coal would cost over double its current price.

The lesson we can draw from the 1984 Plan is that predicting tomorrow's energy sources, or at least those 10 or 20 years out, is virtually impossible. Predicting what demand will be seems rather more achievable though, or at least it was back then. Here it is worth remembering that the demand forecasts of the time were criticised as far too bullish, and even then various interests were



predicting that energy efficiency would have a major impact, that Maui reserves would prove far larger, and so forth. Resisting such wishful thinking was the hallmark of a successful planner.

I will end with a quote from the 1984 Energy Plan.

> *Looking beyond the 15 year planning horizon, it's clear that new hydro reserves will become increasingly expensive and difficult to develop. The bulk of coal in the North Island and presently proven gas reserves are near to fully committed. Solar, wind and other alternative energy forms are unlikely to provide more than small increments of supply. The lignite reserves of the South Island are the only known indigenous reserves of energy able to offer a substantial and economic long-term development prospect.*

Session 3

Sustainability

Sustainable energy use and management

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ABSTRACT

For an activity to be sustainable, it must deliver ecological integrity, social equity and economic prosperity simultaneously. Particular constraints include the ability of the biosphere to provide material and energy resources and to absorb emissions and wastes; quality of life for everyone; and technical and financial feasibility. The most commonly accepted definition of sustainable development is "Development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs". New Zealand's current energy supply and use is clearly not sustainable on this basis, particularly due to on-going dependence on fossil fuels. Both demand-side and supply-side initiatives are needed. While projected deployment of acceptable renewable energy supplies is unlikely to significantly reduce overall fossil fuel use in the short term, demand-side options are readily available and are often more cost-effective. Systematic analysis and assessment techniques are available to compare alternative projects in terms of the sustainability criteria. Without them the best option is often not obvious. Energy accounting, based on the first law of thermodynamics, allows primary fossil fuel use to be minimised, but does not focus on reducing energy end-use nor does it take account of energy "quality" and non-energy aspects. Pinch technology and exergy analysis use the second law of thermodynamics to both minimise end-use demand and consider the relative quality of different forms of energy. Life cycle assessment (LCA) explicitly includes non-energy resources and emissions in a holistic ecological view of the process from extraction of resources to ultimate disposal. An important issue is that the final assessment requires comparisons between quite different environmental impacts. Ecological footprinting attempts to combine the range of diverse impacts to a single measure—the land area to support that activity. It can also include all the indirect impacts of an activity as commodities and services are drawn from other sectors of the economy. Some existing technology options for some domestic and industrial end-use applications were analysed in terms of their energy sustainability and barriers to implementation. It was shown that scientific and engineering analysis has an important role in defining a more sustainable future energy use path. Market mechanisms need to be modified to carry <u>all</u> important information in the price signal and convey enough benefit to the consumer-investor. While many environmental costs remain externalities, less sustainable and/or supply-side options are often mistakenly favoured.

INTRODUCTION

Energy use is critical to maintaining our present way of life. Currently, a significant fraction of this energy comes from fossil fuels. Also emissions of CO_2 from combustion of fossil fuels contribute a large part of the "greenhouse effect" that is postulated to lead to significant climate change impacts over the next 100 years. Clearly, continuation of the current energy supply and use paradigm is a high-risk approach.

This paper will explore sustainable energy use and management. In particular, it will:

a) attempt to define what is meant by sustainability;
b) examine the sustainability of New Zealand's energy supply and end-use;
c) describe some systematic analysis and assessment techniques available to compare alternative energy supply and utilisation approaches in terms of sustainability; and
d) illustrate these techniques via case studies of existing technology options for some domestic and industrial applications including identification of barriers to implementation of more sustainable options.

SUSTAINABILITY

One of the most widely accepted and morally defendable definitions of sustainable development was developed by the Brundtland Commission (WCED 1987). It is:

> *"Development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs."*

However, as discussed by Mitchell et al. (2004), sustainability is a multi-dimensional concept (Figure 1). There are environmental, technical, economic, social and cultural constraints. Sustainability is achieved when all of these constraints are met simultaneously as represented by the earth in the middle of Figure 1. Particular constraints include the ability of the biosphere to provide material and energy resources and to absorb emissions and wastes (that is, ecological integrity); meeting human expectations and aspirations (that is, providing quality of life for everyone or social equity); and the technical and financial feasibility (that is, providing economic prosperity). Too often an activity is declared sustainable but the analysis only considers one or sometimes two of these dimensions.

From an environmental perspective alone, energy sustainability requires the draw down of fossil fuel energy reserves and emission of greenhouse gases, particularly CO_2, to be minimised.

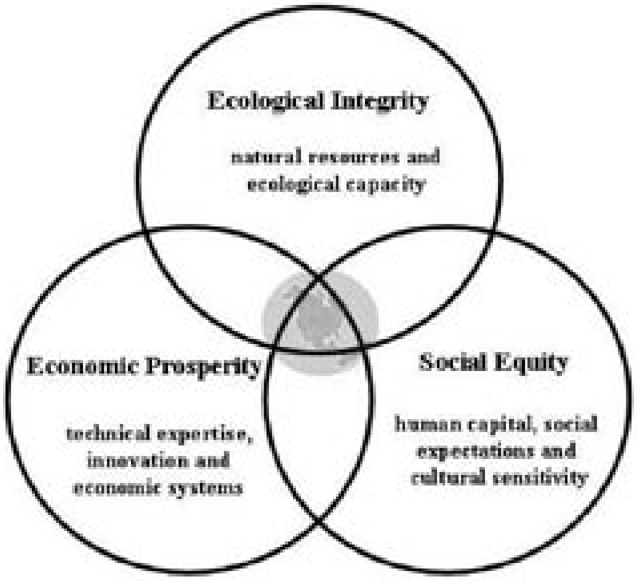

Fig. 1 Multi-dimensional nature of sustainability (adapted from Mitchell et al. 2004).

NEW ZEALAND ENERGY SUPPLY AND DEMAND

Figure 2, taken from the New Zealand Energy Data file (MED 2004), shows diagrammatically the energy flows in New Zealand in 2003. New Zealand is highly dependent on non-renewable fossil fuels for its primary energy (renewable sources account for only 29% of the total). Only about two-thirds of the primary energy is actually delivered as consumer energy and another 60% of the consumer energy is wasted as part of the final end-use. Electricity generation has a greater fraction of renewable sources with about 60% due to hydro and geothermal on a primary energy basis (70% renewable on a consumer energy basis).

Figure 3 shows predictions of energy demand and supply through to 2025 assuming energy efficiency increases about 0.5–1.0% pa above the normal rate (MED 2003). Although renewable sources increase dramatically they struggle to keep up with projected demand so the on-going dependence on fossil fuels remains. In addition, there are other influences. The Kyoto Protocol has been ratified and will come into force now that Russia has signed; dry hydro years were experienced in 2001 and 2003; the output of the Maui gas field has been re-determined such that depletion is imminent; the Iraq war continues; there are predictions of peak oil world-wide; and some claim that climate change is already being experienced as evidenced by the frequency of extreme weather events.

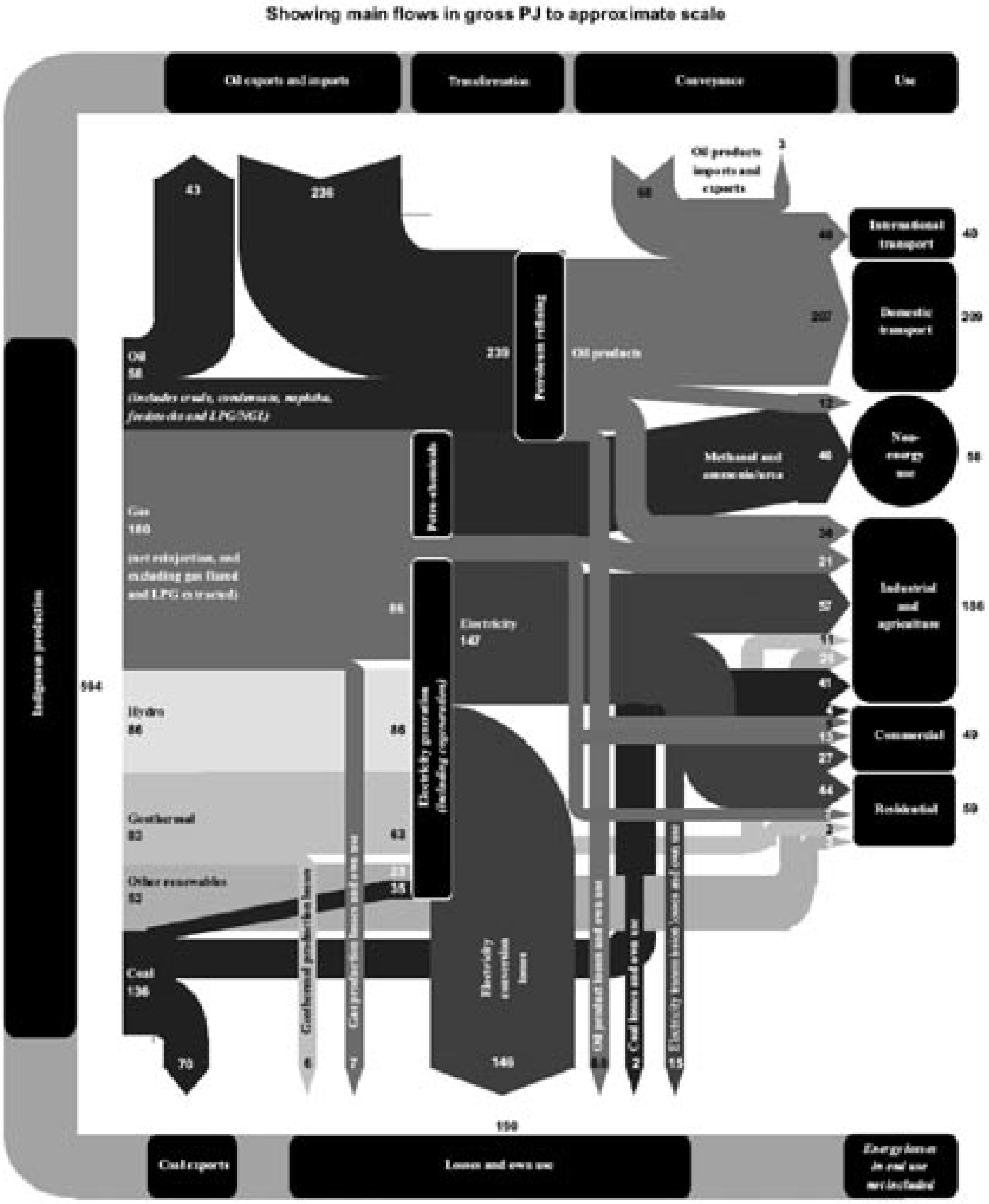

Fig. 2 New Zealand's energy flow in 2003 (source: MED 2004).

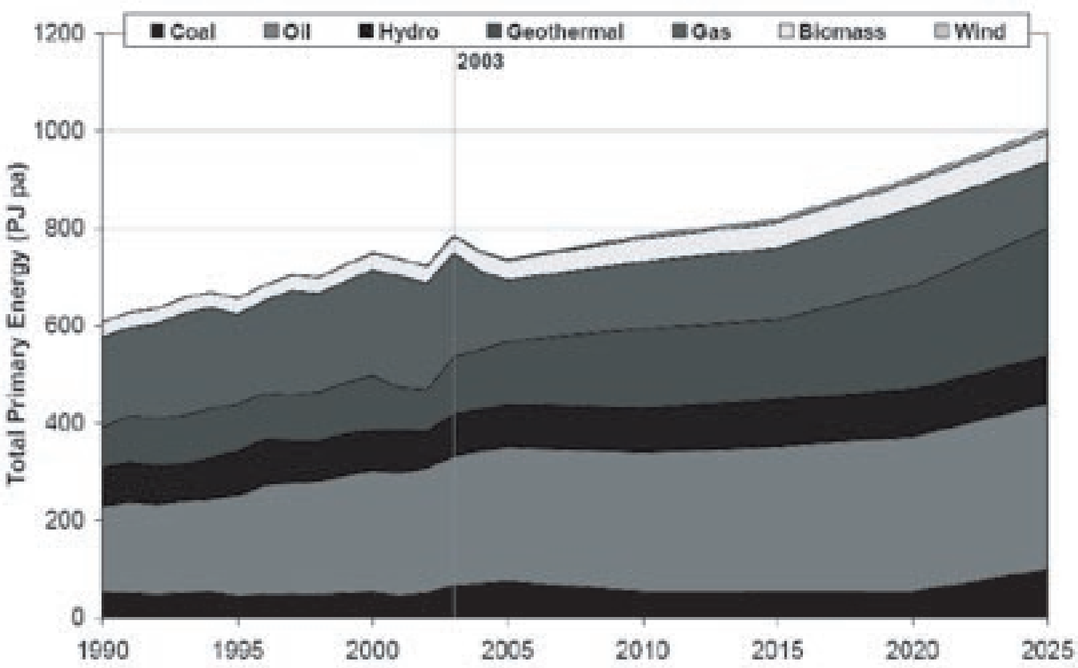

Fig. 3 New Zealand's total primary energy supply 1990 to 2025 (source: MED 2004).

The New Zealand energy supply and demand scene is clearly far from being sustainable given the earlier definitions. So what is sustainable? Man-the-hunter-gatherer had a 120 W lifestyle—2500 calories of food per day plus a bit of firewood. Man-the-New Zealander has about a 4 kW lifestyle on a consumer energy basis, while man-the-American has about a 7 kW lifestyle. It is unlikely that people will be willing to revert to a hunter-gatherer lifestyle. As shown conceptually by the solid line in Figure 4, there is currently a strong link between perceived quality of life and energy use. The dotted line shows a possible path under business-as-usual (BAU) leading to significant climate change, while the arrow shows the desired direction for sustainable development i.e. reduced use of fossil fuel as well as improved quality of life.

Alternatively, energy sustainability is when energy demand and renewable supply converge. As shown in Figure 3, energy demand continues to increase so while projected deployment of acceptable renewable energy supplies is also predicted to increase, the gap continues to need to be bridged by fossil fuels.

Both demand-side (end-use) and supply-side initiatives are needed to close this sustainability gap within a reasonable time-frame. Unfortunately, many assessments concentrate on supply-side options and largely ignore the demand-side (e.g., NZBCSD 2004). This is despite demand-side options being readily available, often being more cost-effective and incremental than supply-side options, and often delivering improved quality of life while reducing energy use. However, there are often significant barriers to the implementation of demand-side measures.

ANALYSIS TECHNIQUES

In order to make good decisions about options and opportunities to improve energy sustainability, systematic and rigorous analysis techniques are required. The following sections briefly describe a small selection of the available energy management analysis techniques.

Sankey diagrams

One of the most basic techniques is a mass and energy balance based on the first law of thermodynamics. The Sankey diagram is an energy accounting method that shows energy flows or energy balances diagrammatically highlighting inefficiencies. Figure 2 is an example at the national level.

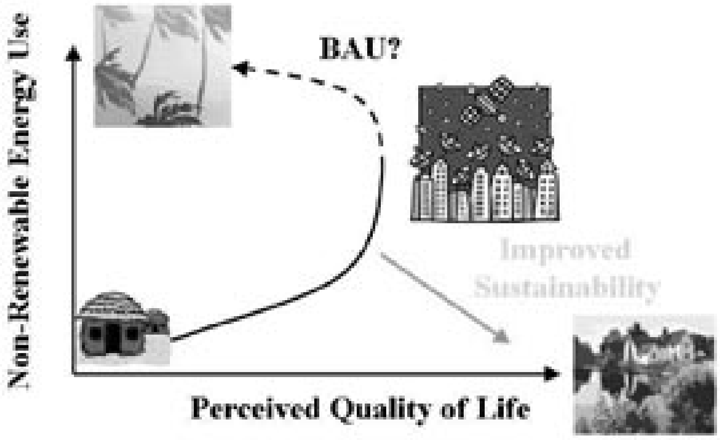

Fig. 4 Conceptual relationship between quality of life and energy use showing a possible path under business-as-usual (BAU) leading to significant climate change and the direction desired for sustainable development.

Pinch technology

The second technique is pinch technology which uses some second law of thermodynamic principles in addition to the first law (e.g., Smith 1995). In any industrial process there are often a number of hot streams that require cooling. Similarly, there are a number of cold streams requiring heating. These can be represented by composite hot and cold curves on a plot of temperatures versus the required heat flow. If heating and cooling are provided separately, then for the example shown in Figure 5a, there is a need for 250 kW of heating (e.g., via a steam boiler) plus 260 kW of cooling (e.g., cooling water or via a refrigeration system).

However, if a hot stream is at a higher temperature than a cold stream, then heat recovery between streams is possible thereby reducing the external need for both heating and cooling. The amount of heat recovery can be shown by moving the cold composite curve under the hot composite curve. The amount of heat recovery is constrained by the need to maintain a temperature difference between the hot and the cold composite curves. At the closest approach point, called the pinch, the heat recovery is most highly constrained. The capital cost of the heat exchange equipment depends on the temperature approach and there is a trade-off between capital costs and energy use. For the same example, Figure 5b shows that for a temperature approach of 10°C, up to 220 kW of heat recovery is possible and the minimum amount of external heating and cooling can be reduced to 30 kW and 40 kW respectively. These are thermodynamically rigorous targets that cannot be bettered so they can be used to assess whether significant improvement to the existing process is possible. Thus a pinch analysis can define the potential for improvements in energy efficiency by heat recovery.

Pinch technology also allows design of heat exchanger networks plus the optimal design and selection of utilities systems including boilers, cogeneration, heat pumps, refrigeration and many other process operations.

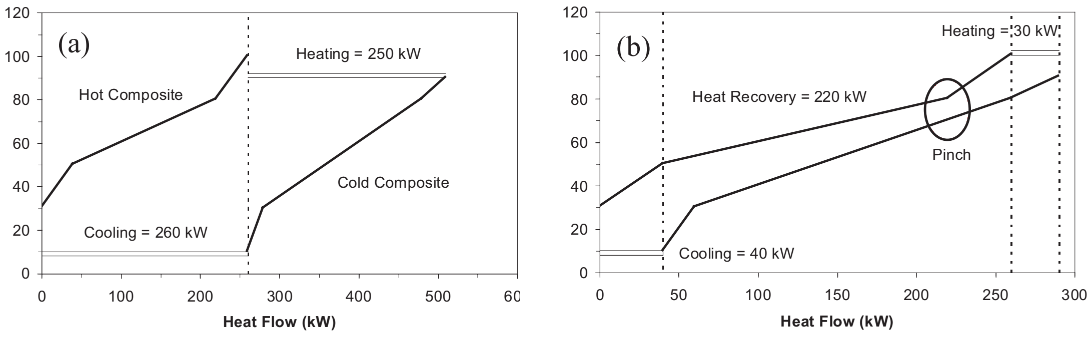

Fig. 5 Pinch technology example: (a) hot and cold composite curves without heat recovery; (b) composite curves with minimum temperature approach of 10°C showing the pinch.

Exergy analysis

Different forms of energy are more or less valuable. That is, they have different quality. For example, most would probably agree that 1 kWh of electricity is more valuable than 1 kWh of heat at 60°C. However, which is more valuable: 1 kWh of heat at 60°C or 1 kWh of cold at –20°C? Exergy analysis allows a thermodynamically rigorous analysis of alternative energy supply, transformation and end-use systems by reducing all these to "potential to perform work" based on the first and second laws of thermodynamics (e.g., de Swaan Arons et al. 2004). Note that pinch technology is essentially a heat-only exergy analysis.

Life cycle assessment

The above techniques focus on energy use and transformations, but in many situations non-energy aspects can be just as important. Nuclear energy is a classic case where disposal of radioactive waste becomes a key environmental issue. Life cycle assessment (LCA) takes a more holistic ecological view of producing a product or service including extraction of resources, manufacture, use, reuse, recycling and disposal (Figure 6). As well as energy, other resources and emissions of wastes are explicitly taken into account. LCA is a bottom-up analysis as it builds up from detailed analysis of the component parts and processes.

Figure 7a shows an example of the classic comparison between a paper and polystyrene cup for coffee (Hocking 1991). Initial reactions are usually that the paper cup is more sustainable due to the polystyrene being synthetic and non-biodegradable. From an energy use perspective the opposite is true—the paper cup results in greater energy use because of the processes needed to produce paper from wood. But if other factors such as emissions to water and air and disposal are taken into account, the preferred cup becomes less obvious.

LCA analyses raise the issue of which environmental impact is better or worse—high energy use and water and air emissions (for the paper cup) or a small amount of non-biodegradable material (for the polystyrene cup). Additionally, the best answer might be different in Russia than in New Zealand. With fast flowing rivers and strong prevailing winds in New Zealand providing ample dilution, New Zealanders might prefer the water and air emissions, whereas Russians might prefer to add the non-biodegradable solid waste to a disused salt mine.

Figure 7b shows an alternative LCA analysis for the same problem that attempts to group the impacts into general categories (AELA 2004). While useful, the best option is still not totally clear as it depends on what aspects are most valued or objectionable. For example, which is worse—emissions of carcinogens or ecotoxicity?

It is worth noting that from an energy perspective, the coffee in the cup has an even larger energy content than either cup so going without coffee altogether gives the biggest benefit both in terms of energy use and possibly health, and is probably the best option all around.

Ecological footprinting

Ecological footprinting attempts to overcome the limitation of LCA by combining the range of diverse impacts to a single measure—the land area necessary to support that activity. Table 1 shows the results of an analysis for New Zealand by McDonald & Patterson (2004). It shows the amount of land estimated to sustain the New Zealand population. The amount is only two-thirds of the available land so in this sense New Zealand can claim to have a sustainable economy. Of the developed world only New Zealand, Canada and Australia live within their land-based carrying capacity. The world as a whole needs about 30% more land than there is on the planet, which is clearly not sustainable.

The breakdown is shown in Table 2 for a selection of provinces. There are some obvious results such as Auckland which has a much larger footprint than its actual area and is thereby subsidised by the rest of New Zealand. However, the more detailed analysis shows some less intuitive results with Otago having the highest footprint per person while Auckland is now the lowest. The reason is a combination of differences in land productivity for the various regions and differences in

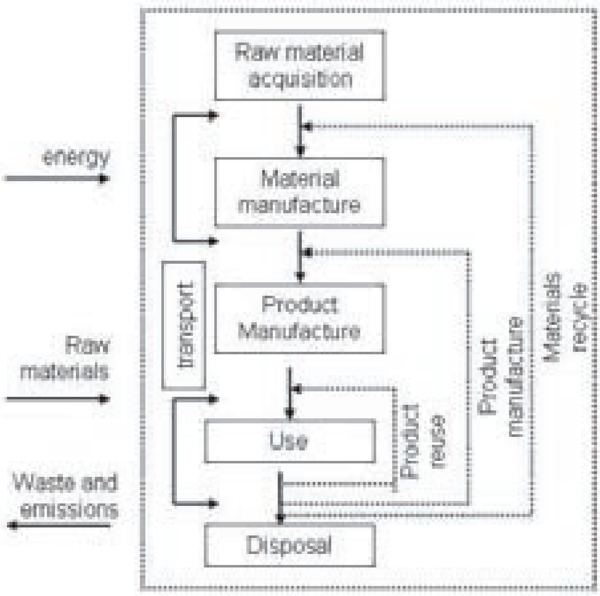

Fig. 6 Principles of LCA.

(a)

	Paper	Polystyrene
Raw Materials (per cup)		
wood	33 g	0
petroleum	4.1 g	3.2 g
Utilities (per metric ton)		
steam	10,000 kg	5,000 kg
power	980 kWh	150 kWh
cooling water	50 m^3	154 m^3
Water Effluent (per metric ton)		
suspended solids	50 kg	trace
BOD	40 kg	0.07 kg
organochlorines	6 kg	0
metal salts	10 kg	20 kg
Air Emissions (per metric ton)		
chlorine	0.5 kg	0
chlorine dioxide	0.2 kg	0
reduced sulfides	2.0 kg	0
Recycle Potential		
after use	low	high
Ultimate Disposal		
incineration recovery	20 MJ/kg	40 MJ/kg
mass to landfill	10.1 g	1.5 g
biodegradable	yes	no

(b)

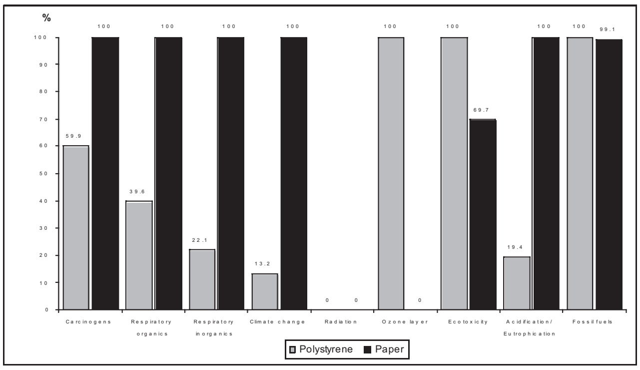

Fig. 7 LCA example comparisons between paper and polystyrene coffee cups (adapted from (a) Hocking 1991 and (b) AELA 2004).

economic activity in terms of the agriculture and industrial balance. Interestingly, Nelson which has an alternative lifestyle reputation has a low per capita rating but still exceeds its own carrying capacity by a factor of 2.

Such an analysis takes a top-down approach that includes all the indirect impacts of an activity such as commodities and services that are drawn from other sectors of the economy.

Figure 8 is a so-called tree diagram of the CO_2 emissions associated both directly and indirectly with the tourism sector (Patterson & McDonald 2004). While tourism has high direct emissions, particularly as a result of the international and domestic travel component, the indirect impacts of commodities and services drawn from other sectors of the economy such as the food and beverage supply chain are also large. For example, tourists eat food and the food industry needs financial services and people working in financial services need food, etc. Such indirect flow-on effects should not be neglected when comparing options for improved sustainability. Once all travel is included, the tourism sector accounts for about 22% of the total New Zealand energy use, making it the second largest sector after basic metals.

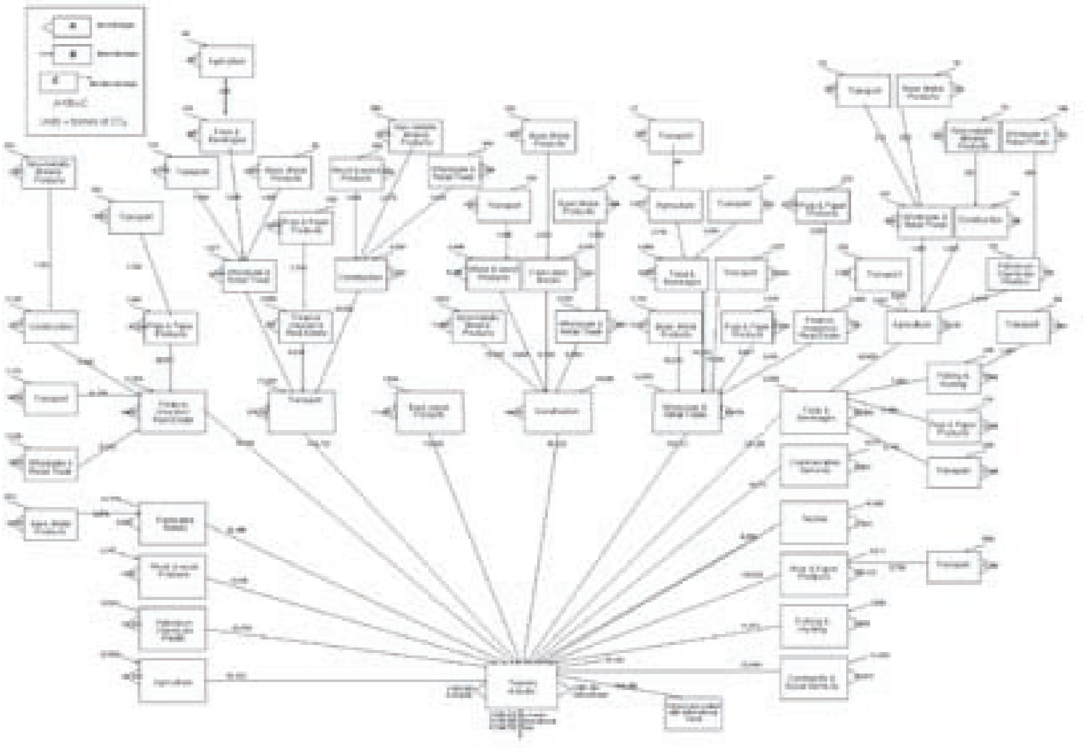

Fig. 8 Direct and indirect CO_2 outputs from the tourism sector 1997/98 (Patterson & McDonald 2004).

Table 1 New Zealand's ecological footprint by land type 1997/98 (usable land in NZ = 17,783,949 ha)

Land type	NZ land (ha)	Land from other nations (ha)	Total land (ha)	Total land (ha per capita)	Total land (% of total)
Agricultural land	6,399,410	1,636,650	8,036,060	2.12	68.8
Forest land	595,430	148,980	744,410	0.20	6.4
Degraded land	844,100	115,150	959,250	0.25	8.2
Energy land	1,409,960	534,980	1,944,940	0.51	16.6
Total	9,248,900	1,435,760	11,684,660	3.08	100.0

Table 2 Selected provincial footprints, land productivity rankings and land loading 1997/98.

Region	Ecological footprint (ha/person)	Land productivity ranking	Land loading (%)
Otago	5.41	15^{th}	47
Canterbury	3.57	13^{th}	48
Waikato	2.87	2^{nd}	52
Wellington	2.40	10^{th}	142
Auckland	2.00	3^{rd}	482
Nelson	1.86	14^{th}	218
New Zealand	3.08		66

ENERGY MANAGEMENT CASE STUDIES

Compact fluorescent lights (CFLs)

Figure 9a shows the electricity supply chain providing light using an incandescent lamp connected to the Huntly power station. Huntly generates electricity from gas or coal with about 35% efficiency, and there is about 5% loss in each of the national transmission grid and local distribution networks so the customer only receives about 31% of the original primary energy (it should be noted that this diagram ignores losses and energy use in the gas or coal supply chains). At the customer's end there is a further 1% line loss in the local wiring, but the lamp only converts 2% of the energy into light and the light fitting means that 50% of this light is ill-directed. Consequently only about 0.3% of the original energy ends up as useful light! In other words to get 1 unit of light requires 320 units of gas to be burnt. The other 319 units of gas energy end up heating the environment.

So what alternatives are there? A supply-side option is to use a combined cycle gas turbine (CCGT) generation plant instead of Huntly. The efficiency of such plants is about 50% so the 1 unit of light now requires 224 units of gas, which is a 30% reduction in fossil fuel used (Figure 9b). New Zealand is moving this way as new gas-fired generation uses CCGT technology.

A demand-side option is to use a compact fluorescent light (CFL) instead of the incandescent lamp. A CFL is about 5 times more efficient so the losses reduce from 98% to 90%. In other words, a 20 W CFL produces about the same light as a 100 W incandescent bulb. Translated through the supply chain this means that the primary energy use is reduced to 64 units per unit of light, even if Huntly is still used (Figure 9c). This is an 80% reduction in energy use. The benefit of a demand-side technology addressing the most inefficient part of the supply-chain is clear. Of course, benefits are cumulative so if a CFL is used as well as the CCGT then gas use is further reduced to 45 units of gas per unit of light.

Table 3 shows the investment case for a CFL relative to incandescent bulbs. It looks a great deal—$23 versus $93 over 6000 hours of operation. So why has uptake of CFLs been so poor? Barriers include perceived ugliness, dislike of the "cold blue" light from some CFLs, the ramp-up period for some CFLs, doubt over claims of longer life and fitting incompatibilities among others. For example, how many people have bought a CFL only to get home and find they bought one with a screw fitting rather than a bayonet fitting. Why stores seem to stock predominantly screw fittings when most domestic fittings are of the bayonet type is a mystery. Hopefully it is because all of the bayonet fittings are sold so rapidly that only the screw type is left, but this seems unlikely.

CFLs are also a case where improved quality of life through better lighting levels can be achieved as well as better energy efficiency. A 100 W equivalent CFL provides more light yet still uses 75% less power than a 60 W incandescent lamp.

Table 3 Comparison of costs for compact fluorescent lights (CFLs) and incandescent bulbs over 6000 hours of operation.

Type	Incandescent	CFL
Price ($)	1	5
Life (hours)	2,000	6,000
Power (W)	100	20
Energy (kWh)	600	120
Energy cost ($)	90	18
Total cost ($)	93	23

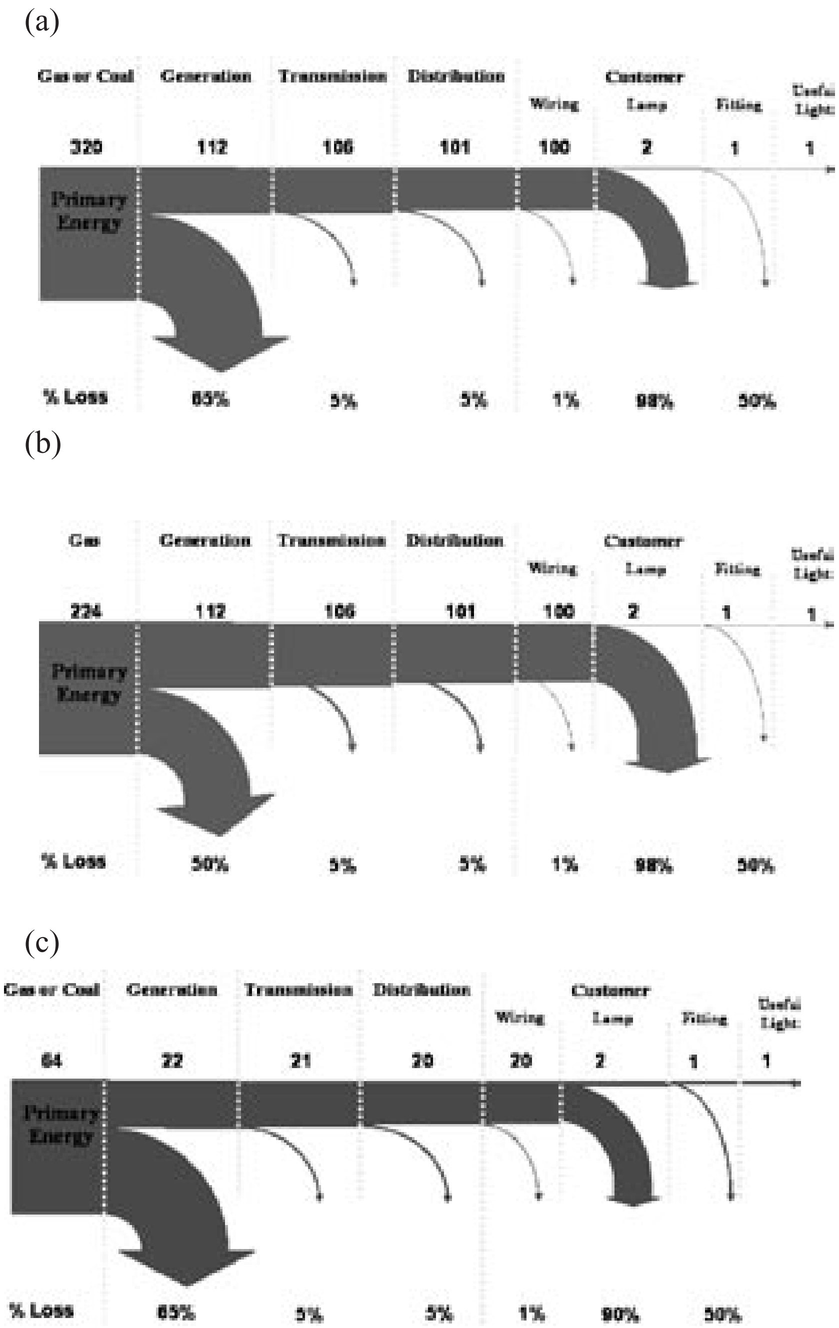

Fig. 9 Sankey diagram showing the electricity supply chain providing light (a) an incandescent bulb supplied by Huntly power station; (b) an incandescent bulb supplied by a CCGT power station; (c) a CFL supplied by Huntly power station.

Demand response

The next energy management example is one that was known as electrical load shifting but is now referred to as demand response. Demand response can take many forms, but only shifting electricity use from peak to off-peak times will be considered here.

Such demand response is beneficial to some customers because they may be able to reduce costs by shifting from high tariffs to lower tariffs. Hopefully, this price reduction is because the electricity supply chain costs are reduced but unfortunately tariffs do not always accurately reflect actual costs because they are a time-weighted average. For example, if the Cook Strait cable is down, then cost of supply in the North Island can be much higher than on average whereas the South Island costs might be lower, yet most tariffs remain unchanged.

So is demand response more sustainable? It can be argued that it is because it allows the renewable content of the electricity to be kept higher even though energy use may not reduce. However there are significant issues. Demand shifting needs to be automated so it does not require on-going supervision and it needs to be flexible so it can react to less predictable events; for example, no wind in a wind farm area. In addition, the load shifting should not compromise the performance of the process being utilised.

Industrial coldstores have considerable potential for demand response (Brookes et al. 1999). Figure 10 shows the response of the air and palletised product temperature when the coldstore is pre-cooled over the weekend and then turned off during subsequent weekday daytime peak periods. The product in the store provides a large thermal inertia so the refrigeration can be turned off for quite long periods without significant temperature rises.

A controller was developed to automatically perform such load shedding in response to varying price signals sent by the electricity supplier (Cleland 2003). The controller attempts to optimise the operation of the refrigeration to both minimise energy cost and to maintain stored product quality. Essentially the controller tries to integrate the electricity supply and the coldstorage businesses using information and communication technology for the benefit of both parties.

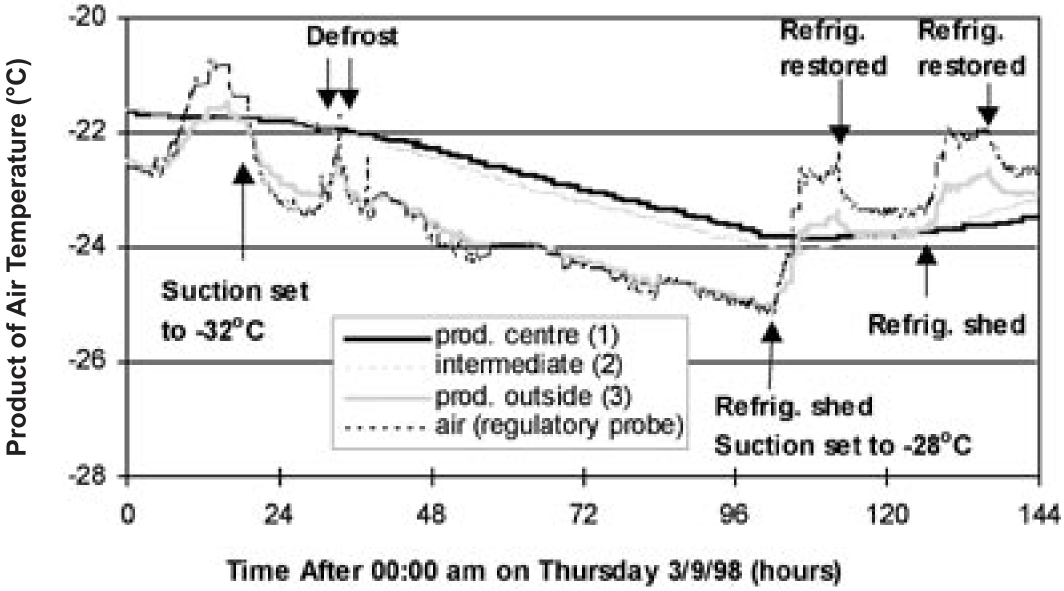

Fig. 10 Air and product temperature responses in a coldstore during a load management trial that involved a daily shut-down of the refrigeration with one fan on after pre-cooling for 3 days (Brookes et al. 1999).

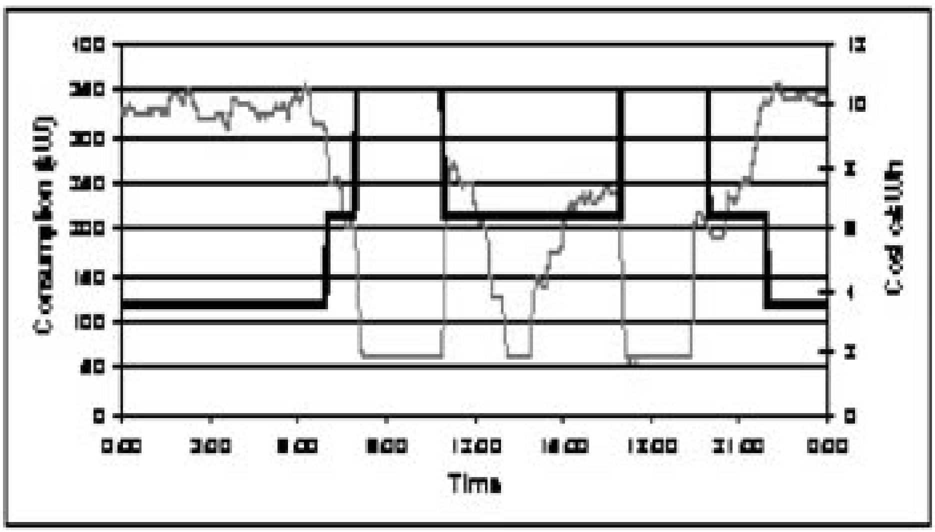

Fig. 11 Average daily coldstore electrical load (thin line) when controlled against the indicated cost profile (bold line) by a prototype demand response controller (Cleland 2003).

Figure 11 shows how the controller performed in industrial trials. The bold dark line is the cost signal sent to the controller and the thinner line is the power demand. It can be seen that load is shifted but occasionally the refrigeration operates even when price is high such as just after midday, because the value of the stored product is many times higher than the value of the electricity. If product quality is likely to be compromised because of loss of temperature control then it is best to use energy to correct it, irrespective of the price.

The cost savings were about 10–20% compared with simpler time-based control strategies although total energy use was similar. However such a technology is quite difficult to implement because it involves close integration of at least two quite different businesses with quite different objectives. Also the financial benefit is split between at least five businesses—the product owner, the coldstore owner/operator, the lines company, the national grid operator, the retailer and the generator—so it can be difficult to capture the benefit in one place to make the investment decision simple to implement.

Hot water heating

Hot water heating for sanitary uses represents about 7% of New Zealand's total energy use and about 18% of electricity use. About 70% of this occurs in the residential sector, of which about 85% use electric hot water cylinders (HWCs).

Demand response is already practised via ripple control systems because of the thermal storage capacity of the HWCs. Customers get lower tariffs if they allow the line company to use their HWC for load shifting, generally to manage transmission and distribution line loadings. Most customers never notice it happening and, if they do get a cold shower, the resident teenagers probably cop the blame rather than the power company. Essentially the risk and cost of getting the load shifting slightly wrong is not high, so a less sophisticated control system can be justified than for industrial coldstores.

In terms of improving energy efficiency there are many simple housekeeping opportunities that deliver good economic and environmental outcomes, e.g., cylinder wraps, lower thermostat settings, leak prevention, low flow shower heads etc. However, the best type of water heating system to use is more difficult to determine.

The first decision is whether it would be better to use gas directly instead of electricity generated from gas. As the Sankey diagram in Figure 12 shows, the direct gas options use 40% less gas than electricity via a CCGT. Gas also has the advantages that gas hot water cylinders have faster recovery or gas can be installed as on-demand units without storage losses. Counteracting this is the need for an extra energy connection with its associated fees.

Three alternative technologies are solar-thermal systems, heat pumps and cogeneration (e.g., Whispergen). Solar-thermal systems are well documented. Heat pumps use the refrigeration cycle to extract heat from the outside air and compress the refrigerant up to a higher pressure and temperature so it can be used to heat water (Figure 13). Raising the temperature requires some electrical energy input to the compressor and fans but each unit of electricity used can produce about 3 units of water heating so the overall conversion of gas energy to hot water is 150% if a CCGT power stations is used.

Table 4 compares solar-thermal and heat pump water heating options against standard electrical heating on an annual basis. First, contrary to popular belief, solar-thermal systems generally only reduce energy use by about two-thirds on average. Particularly over winter there is not enough sun to do all the water heating, so electric boost is needed to maintain water temperature. Given that the New Zealand electricity system is winter-constrained, solar has less benefit in terms of reducing fossil fuels than might be imagined. It could be argued that in winter a wet-back could be used on an efficient wood burner used for space heating to fill the solar gap. This is a more environmentally sustainable option but will further increase the capital cost which is already higher than a heat pump (that is, it may not be economically sustainable). Another issue for solar systems is the control system—solar availability may not match water demand so deciding when to activate the electric boost is quite difficult to optimise.

In contrast, the heat pump option provides about the same reduction in annual electricity use and its performance is more uniform over the year. Its lower initial cost gives a better investment case. However, availability of appropriate heat pumps is currently poor in New Zealand. Inexplicably a New Zealand-developed unit was recently withdrawn from the market. However, it is likely that various hot water heat pump providers will enter the market shortly. Other important issues with the heat pump include the noise of the compressor and the environmental impact of the refrigerants should they escape. However, overall this comparison shows that what initially might appear to be the most environmentally friendly option may not be.

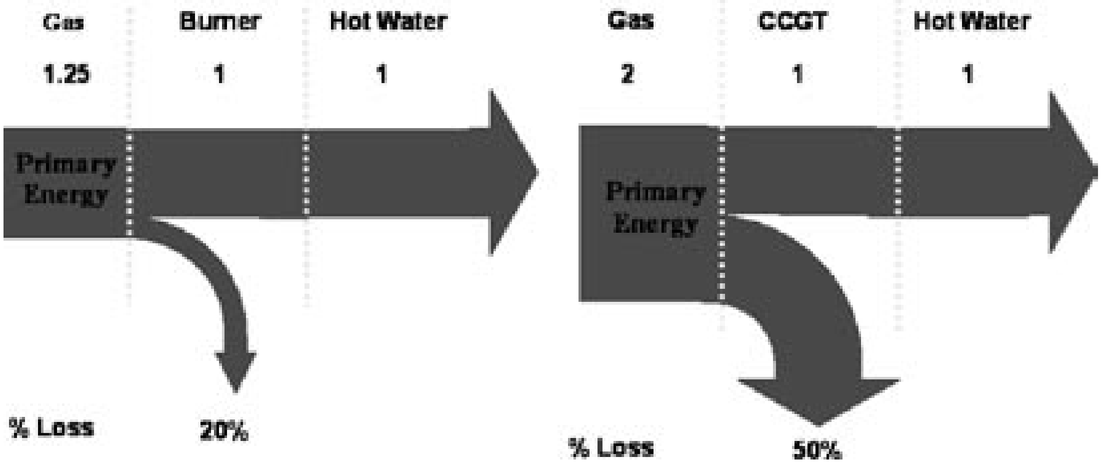

Fig. 12 Comparison of a direct fired gas HWC (left) with an electric HWC supplied via a CCGT power station (right) using Sankey diagrams.

Table 4 Comparison of solar-thermal and heat pump systems for domestic water heating.

	Solar	Heat Pump
Installed cost	≈$3500	≈$2000
Energy savings	60-70%	60-70%
Cost savings	≈$350 pa	≈$350 pa
Payback	10 years	6 years
Winter performance	Poor	Moderate
Availability	Good	Poor
Other issues	Control	Noise Refrigerants

The Whispergen technology was developed in Christchurch as a result of research at Canterbury University (Figure 14). It is based on the Stirling thermodynamic cycle which was discovered about the turn of the century in Scotland—it took the development of the wobble yoke transmission system to allow it to be manufactured in a compact economic form. Whispergen is a form of Combined Heat and Power (CHP) or cogeneration. It is a distributed generation option. It burns a fuel to generate electricity but the waste heat is almost entirely recovered as hot water for both sanitary use or space heating via radiators. It can replace the standard combi-boiler commonly used in Europe. If it is operated in heat-led mode (that is it only operates when space heating or water heating is required), the electricity is produced at 100% efficiency which is far better any thermal power station. In addition, it is quiet because the Stirling cycle uses external rather than internal combustion of the fuel.

So why does every home in New Zealand not have one? Primarily, it is because the capital cost is relatively high, and the energy efficiency is only high when operated heat-led, so they only become economic when the heating season is longer than occurs for most of New Zealand. However, they are starting to be installed in Northern Europe which has a longer heating season.

(a) (b)

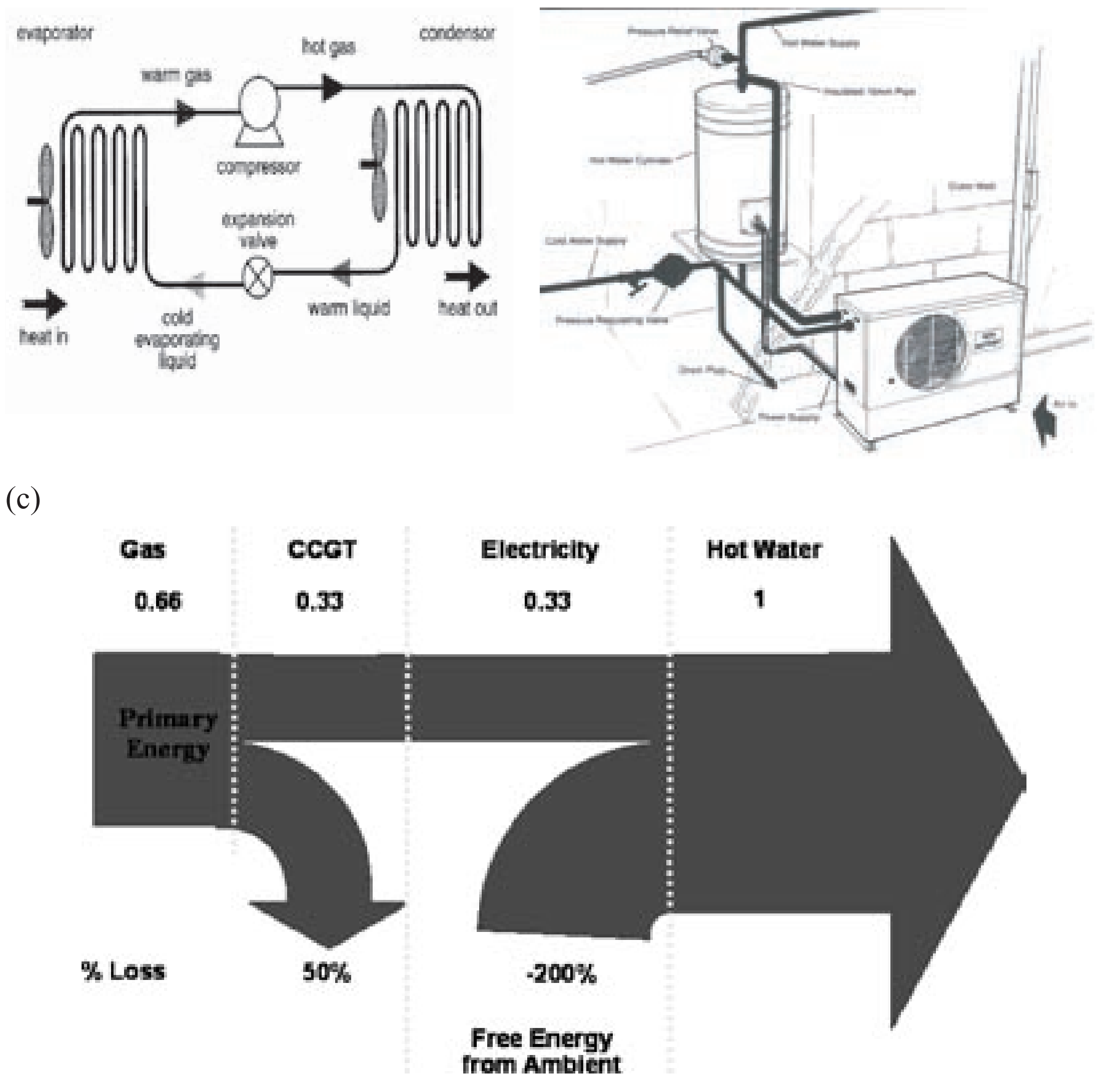

Fig. 13 Hot water heating heat pumps (a) the heat pump cycle; (b) connection to the HWC; (c) a Sankey diagram showing energy flows if supplied by CCGT electricity.

Another important aspect is that while the Whispergen electrical output of 0.5 to 1.0 kW looks well matched to the average domestic load of about 1 kW, in reality the heating loads and electric loads are dynamic and are not always coincident, so at least 20% of the electricity generated must be exported and later re-imported from the grid. Hence, such a technology can help the grid support increased demand without huge investment in infrastructure, but is difficult to operate independently of the grid.

From the exergy perspective outlined earlier, the Whispergen has an exergetic efficiency about double that of direct gas heating. That is, the loss of exergy or work potential is about half that of a direct gas heating system (de Swaan Arons et al. 2004).

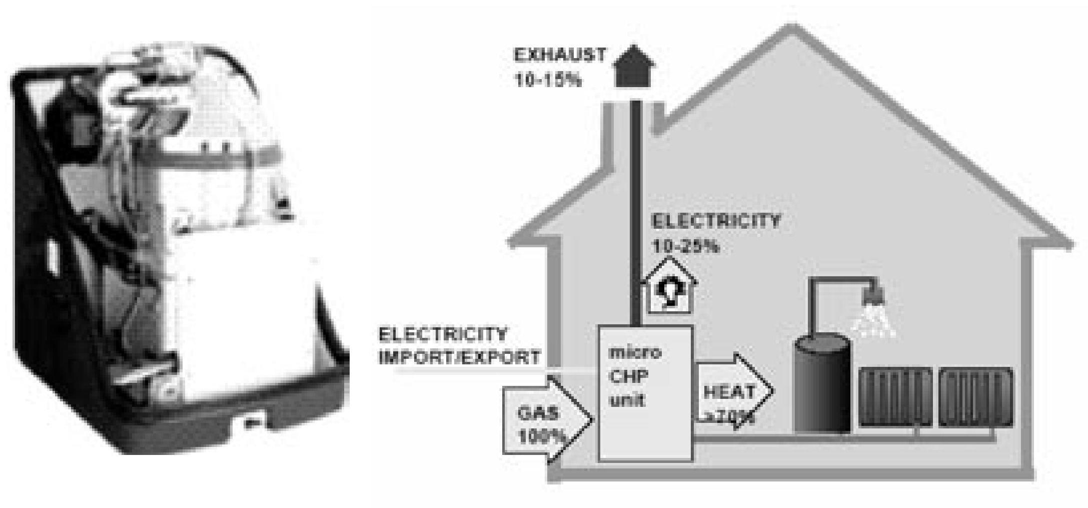

Fig. 14 A Whispergen Stirling cycle combined heat and power unit (left) showing how it can provide electricity, water heating and space heating to a domestic residence (right).

CONCLUSIONS

Significant demand-side initiatives are essential, in addition to supply side options, if New Zealand is to achieve rapid energy sustainability improvement. Energy cannot be looked at in isolation from all of the other environmental, economic and social impacts. Systematic analysis techniques are available to provide technical assessment of options. The results of such analyses are not always intuitive so care must be taken not to commit to promising, but ultimately less sustainable routes.

While market mechanisms can deliver demand-side incentives they are biased towards supply-side options, particularly because many costs to society such as environmental impacts are not fully accounted for and the benefits of demand side options can be difficult to capture because of their distributed nature. Balancing market structures by making them carry all important information in the price signal is essential to convey enough benefit to the customer/investor so that the most sustainable options will be adopted.

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New materials for sustainable energy conversion

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Palmerston North, New Zealand

THE ENERGY CRISIS

"I will get right to the point. **Energy is the single most important problem facing humanity today.** We must find an alternative to oil. We need to somehow provide clean, abundant, low-cost energy throughout the world to the 6 billion people that live on the planet today, and the 10+ billion that are expected by the middle of this century. The cheaper, cleaner, and more universally available this new energy technology is, the better we will be able to avoid human suffering, and the major upheavals of war and terrorism." *Professor Richard Smalley, the joint 1996 Chemistry Nobel Laureate, to a US Congressional hearing in late 2002* (http://www.smalltimes.com/document_display.cfm?document_id=4262).

The concern expressed in this statement was foreshadowed by the British economist E. F. Schumacher 30 years earlier in his book "Small is Beautiful" when he asked what the future of the human race would be if oil were to run out, given that oil is a non-renewable resource, modern agriculture is very energy (oil) intensive, large-scale production is a consequence of cheap oil and large cities are a consequence of cheap oil (Schumacher 1973). The answer to Schumacher's question is even more challenging in 2004 since human society is not only more dependent on oil for both its energy supply and the fabrication of many of the essential products of modern living, but it is also having to face the environmental consequences of a century of uncontrolled nonrenewable resource consumption. It is not surprising, therefore, that sustainable energy production is becoming a major research focus worldwide.

PHOTOVOLTAIC (PV) CELLS

The conversion of sunlight to electricity is an enticing solution to sustainable energy production so it was not surprising that, when reporting the development of the first silicon solar cell by three Bell Laboratory scientists in 1956, the New York Times praised it as "the beginning of a new era, leading eventually to the realization of harnessing the almost limitless energy of the sun for the uses of civilization" (Perlin 1999). Despite the great potential of silicon solar (photovoltaic) cells and fifty years of excellent research to improve cell efficiencies, the cell cost remains too high for widespread public use. Nonetheless, the silicon photovoltaics industry is presently booming, with compounded annual growth rates of 30–40%/year over the last 10 years. The future however may not be so promising. The high quality silicon required for solar cells is produced in large quantities by the semiconductor industry. The processing of crystalline silicon wafers is high-level semiconductor technology, and as such expensive and very capital intensive. The current big question for silicon photovoltaic technology is: What is the future availability of highly purified silicon?

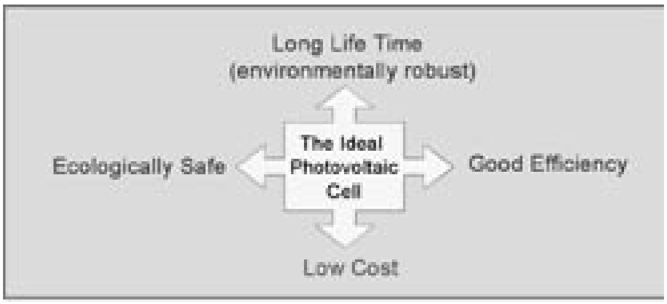


Fig. 1 The ideal photovoltaic cell.

If the cost of silicon solar cells was lower, they could be considered to be the ideal photovoltaic cell (Figure 1). However, two other features should be considered in this regard. Solar cells should have the potential to be flexible and semitransparent for easy integration into different devices and locations and they should be architecturally versatile (adaptable, cosmetic with good spatial properties i.e. colours, texture, size, shape). In addition, they should "harvest" sunlight in all light level conditions and silicon cells require bright sunlight. Fortunately, major advances have been made worldwide with respect to new non-silicon solar cells that could fit all of the above requirements; photoelectrochemical (PEC) solar cells and solid state organic or plastic solar cells. Aspects of both of these technologies are under development in the Nanomaterials Research Centre (NRC), Massey University and this work will be focus of the rest of this paper.

THE GRÄTZEL PHOTOELECTROCHEMICAL PHOTOVOLTAIC CELL

Professor Michael Grätzel of the École Polytechnique Fédérale de Lausanne in Switzerland has developed the first commercially viable non-silicon PEC cell. This so-called liquid junction solar cell or Grätzel cell uses ruthenium polypyridyl-based dyes adsorbed on nanocrystalline films of titanium dioxide (TiO_2) and a conducting liquid electrolyte, all sandwiched between two glass electrodes (Figure 2) (Grätzel 2004). Titanium dioxide is a cheap material widely used as a pigment in paint or paper and as an abrasive in toothpaste and other cosmetic products and is a New Zealand resource; South Island ironsand is incredibly rich in titanium dioxide and the extraction process has been developed in New Zealand (MacKenzie et al. 1991). On excitation by solar radiation the dye ejects an electron, which passes through to the semiconductor conduction band of the titanium dioxide and into the external circuit (line in Figure 2). The now oxidised dye is reduced to its original state by electron transfer from the recyclable reducing electrolyte (typically an iodine/iodide electrolyte). Thus, current flows across the dye/titanium dioxide and solution interface. The efficiency of the liquid-junction cell in converting sunlight to electrical energy is critically dependent both on the light-absorbing properties of the dye and how well the dye is bound to the titanium dioxide surface, as well as the nanocrystalline nature of the TiO_2.

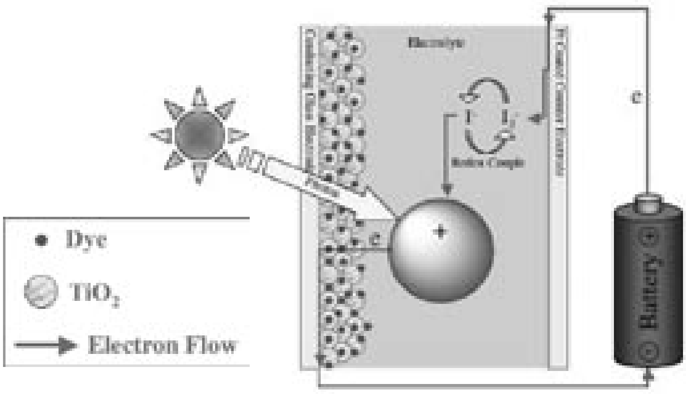


Fig. 2 Diagram showing the operation of the Grätzel dye-sensitised photoelectrochemical cell. The line indicates movement of electrons from the photoexcited dye.

The Grätzel cell has demonstrated laboratory light-to-electricity conversion efficiencies of up to 11%, efficiencies comparable to commercial silicon-based solar cells. In addition, this cell outperforms silicon-based cells at higher temperatures and in low light conditions (http://lpi.epfl.ch/solarcellE.html). Further development of the technology by Sustainable Technology International Limited, Queanbeyan, New South Wales, has occurred and their first commercial production of these "titania" cells was supported by the Australian Greenhouse Office (Phani et al. 2000; http://www.greenhouse.gov.au/renewable/recp/pv/twelve.html). However, the cell construction is a rigid glass "sandwich", limiting their application. In addition, there are significant challenges in sealing in the liquid electrolyte. Thus, there have been major efforts world-wide to develop a solid state Grätzel cell using a solid polymer electrolyte or hole transport material with polymer electrodes. Given the high temperatures (250–400°C) required to make nanocrystalline TiO_2, this is challenging. The most efficient solid state Grätzel cell, reported only recently by Grätzel himself, is 4% (Grätzel 2005).

ARTIFICIAL PHOTOSYNTHESIS USING GRÄTZEL CELLS

The amazingly efficient solar energy collection by photosynthetic organisms is the foundation of almost all energy transfer and generation on this planet. Photosynthetic processes employ light-harvesting complexes to capture dilute sunlight and funnel the energy to reaction centres (e.g., RC, Figure 3) (Ben-Shem et al. 2004). At the heart of this incredible process are the chlorophyll antennae, which contain from 2 to 300 closely spaced chlorophyll molecules embedded in a lipoprotein matrix (e.g., LH1 and LH2, Figure 3). Synthetic porphyrin molecules (Figure 3b) have similar optical properties to those of chlorophyll (Figure 3a) but are much more easily manipulated in the laboratory. Eight years ago, our research group began to investigate the possibility of using arrays of synthetic porphyrins to capture photons and develop one aspect of "artificial photosynthesis", the conversion of light to electricity (the photovoltaic effect) (Burrell & Officer 1998).

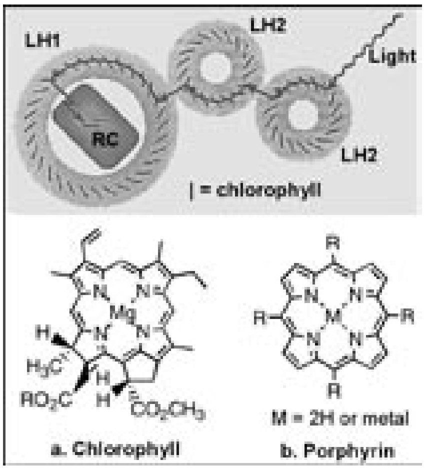


Fig. 3 Cartoon of light absorption by light harvesting complexes (LH1 and LH2) and reaction centre (RC), showing chlorophyll and synthetic porphyrin equivalents.

To effect light-to-electricity conversion in a photosynthetic sense, it is necessary to produce an artificial system that has all of the essential features of chlorophyll arrays found in nature, but the electrons produced are directed to an external circuit instead of a reaction centre. The construction of such a system is conceptually straightforward. The use of porphyrins as dyes in photoelectrochemical (PEC) solar cells provides all the essential features of a photovoltaic device based on chlorophyll. Porphyrins are excellent candidates for dyes, since their light-absorbing properties can be extensively altered, either by modifying the core metal (M, Figure 3b) or by varying the substitution (R, Figure 3b) on the porphyrin macrocycle. Furthermore, binding to an electrode material can be pre-determined with appended functionality such as carboxylic acids.

To achieve this, researchers in the NRC have developed a synthesis of porphyrin arrays of unprecedented versatility (Figure 4) (Burrell & Officer 1998; Bonfantini et al. 2002). Not only does the method allow tailoring of the size and geometry of the array, but also control of the inserted metal (M, Fig. 3b) and attached functionality (R, Figure 1b) (Belcher et al. 1999; Belcher et al. 2002) In contrast to many porphyrin array-forming methodologies, we are able to carry out the chemistry on a multigram scale. In 1996, the publication of the synthesis of a 9-porphyrin array (nonamer, Figure 4) using this methodology placed us at the international forefront of porphyrin array construction (Officer et al. 1996). Although other groups have surpassed this, we have continued to demonstrate the flexibility and versatility of the methodology for the preparation of arrays suitable for attachment to a wide variety of surfaces.

We have also expanded the Building Block 1 (Figure 4) chemistry to produce a wide variety of functionalised single porphyrins that can be bound to surfaces (Campbell et al. 2004). As a consequence, we have attached a number of single porphyrin dyes (selected examples shown in Figure 5) to titanium dioxide and, in collaboration with Professor Michael Grätzel and his research group in Lausanne, improved the light-to-electricity conversion efficiency for porphyrins in the Grätzel cell from below 1% to a current world record of 6.14% (November 2004) (Campbell et al. 2004; Nazeeruddin et al. 2004; Wang et al. unpubl. data). In addition, it has been demonstrated that this occurs with up to 80% charge injection efficiency (dye to titania), comparable to the ruthenium polypyridyl dyes. Preliminary "light-soaking" tests also suggest that the stability of these porphyrins may be comparable to the ruthenium dyes.

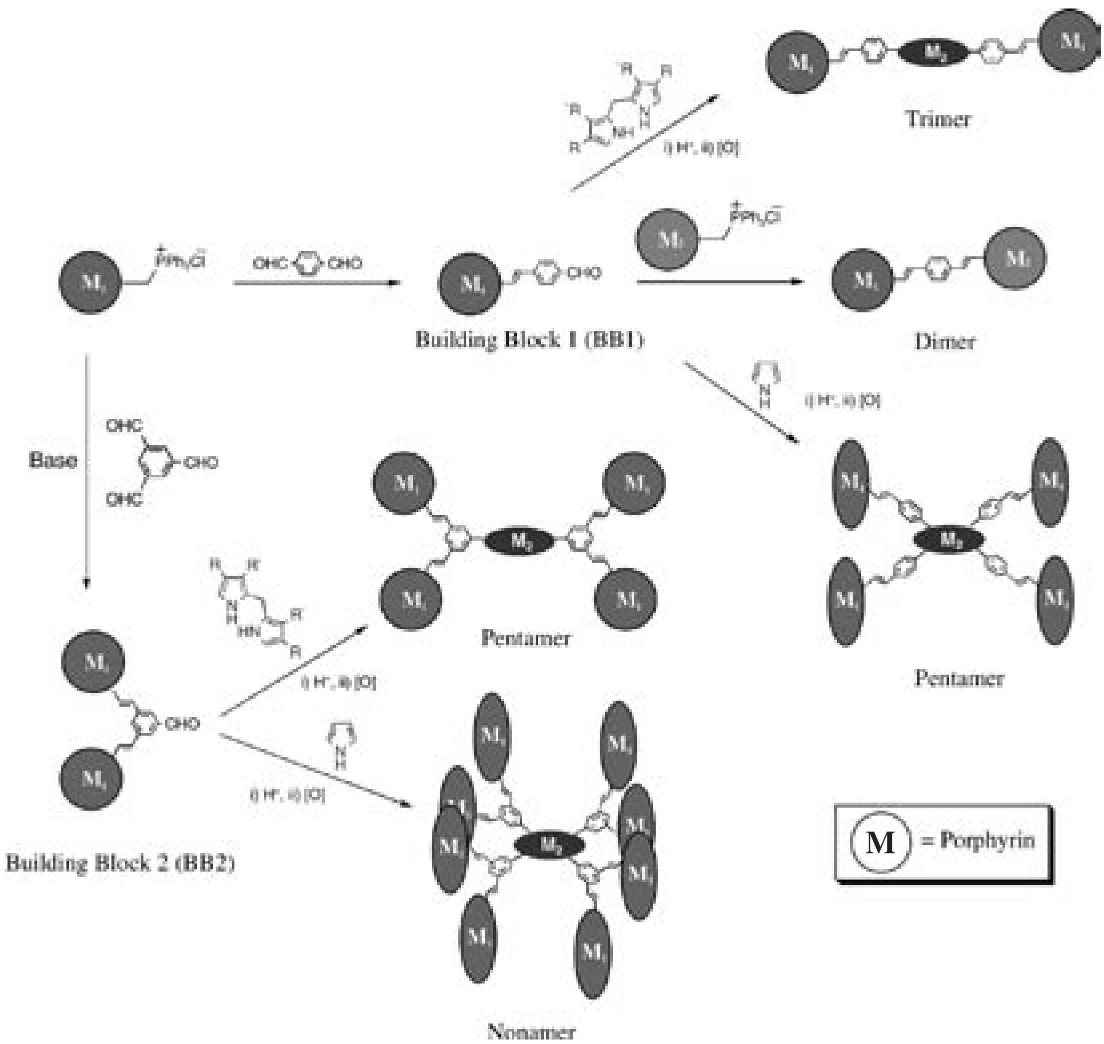


Fig. 4 The building block approach to porphyrin arrays.

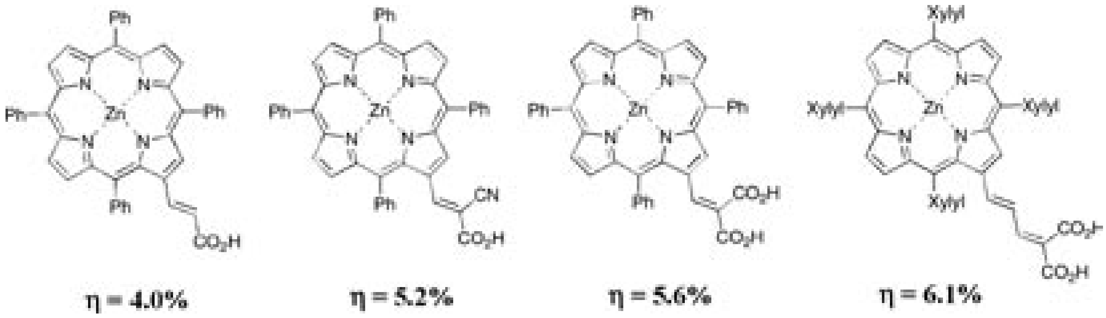


Fig. 5 Porphyrin dye structures showing increasing energy conversion efficiencies (η).

Of some significance is the range of colours that can be obtained using the porphyrin dyes. The porphyrin-sensitised PEC cells range in colour from red through brown to the most efficient cells, which are sensitised by green porphyrins, highlighting the notion of "artificial photosynthesis". This is the first example of green Grätzel cells.

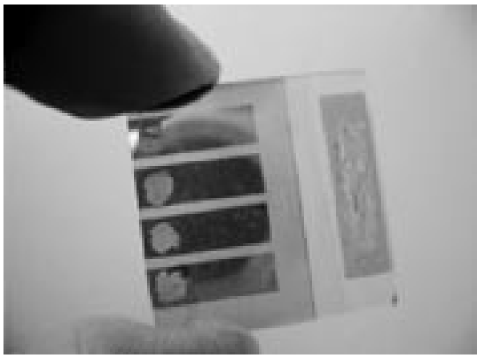


Fig. 6 Photograph of the porphyrin-sensitised solid state heterojunction Grätzel cell.

While we are now able to achieve with porphyrin-sensitised titanium dioxide over half the photovoltaic efficiency obtainable with ruthenium polypyridyl dyes, the porphyrins perform better than this in a solid state heterojunction Grätzel cell (Figure 6) using a hole conductor, giving 3% efficiency compared to 4% for the ruthenium dye. The potential of these porphyrinic materials has led to a joint EPFL/Massey University International PCT patent application (Officer et al. 2004).

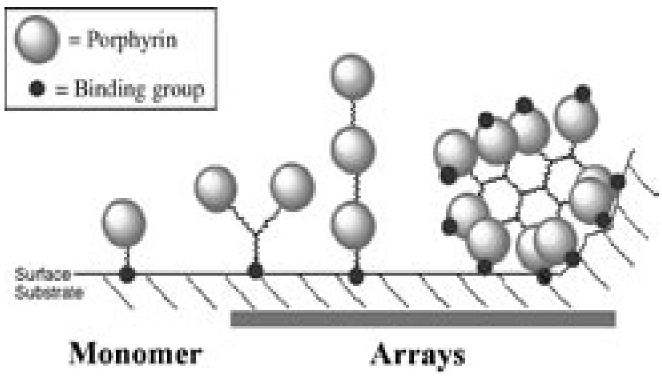


Fig. 7 Cartoon of porphyrin arrays attached to titanium dioxide.

The high light-harvesting efficiency of single porphyrins opens up the possibility of using multiple porphyrins or arrays to improve the efficiency further (Figure 7). Thus, attachment of titanium dioxide binders to the arrays shown in Figure 4 has been undertaken and some arrays bound to titania. Preliminary results suggest that binding of the arrays is weak and therefore efficiencies are poor (Campbell et al. 2004). Further work is under way in this area to design better binding groups and theoretical calculations being carried out by Associate Professor Keith Gordon and his researchers at the University of Otago are assisting in the design of new dyes.

CONDUCTING POLYMER PHOTOVOLTAIC CELLS

Controlling the functional groups attached to light-harvesting porphyrins and porphyrin arrays gave us the opportunity to develop efficient plastic solar (photovoltaic) cells based on organic conducting polymers (CPs) (Wallace et al. 2000). The unique properties of conducting polymers were brought to the fore in 1977 by MacDiarmid, Shirakawa and Heeger, when they discovered that chemical "doping" of conjugated polymers resulted in orders of magnitude increases in electronic conductivity (Chang et al. 1977; Shirakawa et al. 1977). As illustrated in Figure 8, the properties of the undoped and doped forms of conducting polymers are quite different and this can be utilised in a myriad of new technologies such as sensors (Lewis et al. 1999), biomaterials (Wallace & Kane-Maguire 2002), light emitting diodes (Kraft et al. 1998), and polymer actuators (artificial muscles) (Spinks et al. 2003). It has been known for some time that conducting polymers such as poly(phenylenevinylene)s (PPVs) and polythiophenes (PThs) exhibit a photovoltaic effect (Wallace et al. 2005) although solar cells incorporating these materials afford significantly lower light-to-electricity conversions (1–3%) (Arias et al. 1999) than titania or silicon cells (10–23%) (Green et al. 2001). However, the possibility of producing polymer coatings that may function as paints on roofs, vehicles or boats, or even as an integral part of fabrics, to generate electricity from sunlight, is tantalising.

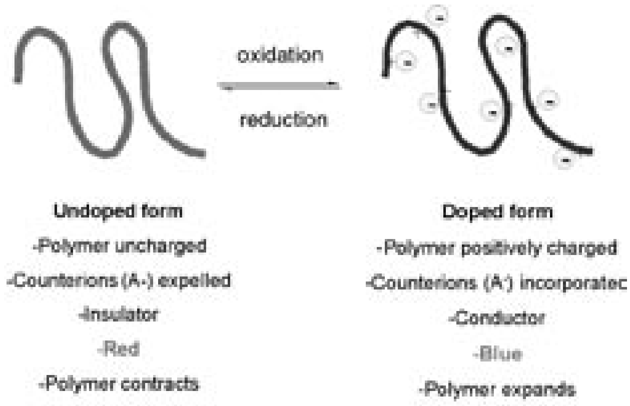


Fig. 8 Cartoon of doped and undoped forms of conducting polymers.

Typically, polymer solar cells are solid state and comprise an active layer sandwiched between two conditioned electrodes such as ITO-glass and aluminium, as illustrated in Figure 9 for one of the best performing cells developed (2.5%) (Shaheen et al. 2001). The active layer may contain only one conducting polymer and an electron acceptor, as illustrated here with the soluble polymer MDMO-PPV and soluble fullerene derivative [6,6]-PCBM in a blend. Other active layer configurations involve two or even three polymers and/or a sensitising dye (Wallace et al. 2000; Brabec et al. 2001). To date, the most efficient polymer solar cells use up to 80% of a fullerene derivative (Shaheen et al. 2001). However, not only is the maintenance of a stable active layer blend of this type problematic, but the high cost of the fullerene makes large-scale production of these cells prohibitively expensive. In addition, the absorption of the conducting polymer is not well matched to the solar spectrum, with an absorption maximum of 500 nm compared to the solar maximum of 700 nm.

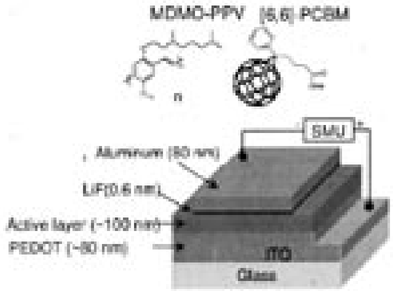


Fig. 9 Solid state conducting polymer solar cell showing active layer components.

A variety of other polymer device configurations have been developed principally with PPV and PTh, as well as polypyrrole (PPy), with mixed success. PEC cells of a structure similar to the titania solar cells, in which a single PTh derivative replaces the titanium dioxide, have also been prepared (Wallace et al. 2005). While their efficiencies are poor, they are appealing in their simplicity and consequently they provide an excellent platform for a systematic study of the nature of polymer photovoltaic cells.

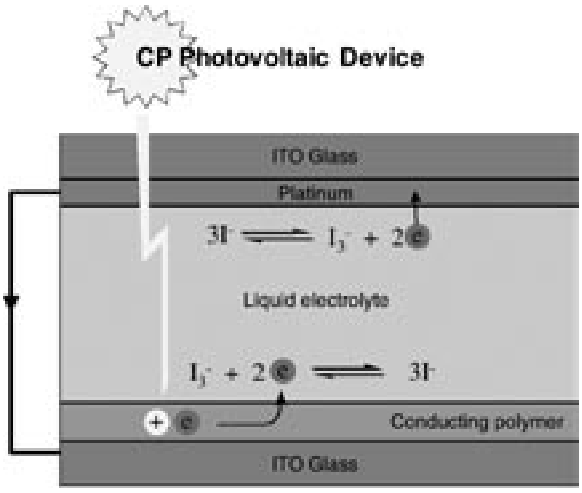


Fig. 10 Cartoon of conducting polymer PEC solar cell.

Over the last eight years, we have built up an extensive collaborative research programme with Professor Gordon Wallace and his research team in the Intelligent Polymer Research Institute at the University of Wollongong, Wollongong, Australia and Dr Paul Dastoor (University of Newcastle) on the development of dye-sensitised conducting polymer solar cells (Figure 10) (Wallace et al. 2005)). During that time, we have studied a number of the features of polythiophene-based PEC solar cells and improved their efficiency by four orders of magnitude to 0.12%, using a porphyrin-containing polythiophene (Cutler et al. 2001; Too et al. 2001; Cutler et al. 2002; Chen et al. 2002; Chen et al. 2003). This is remarkable for a single component polymer device and opens the way for considerably greater efficiency improvements using the traditional active layer components such as fullerene derivatives. This work is currently the subject of a joint University of Wollongong/Massey University International PCT patent application (Chen et al. 2004).

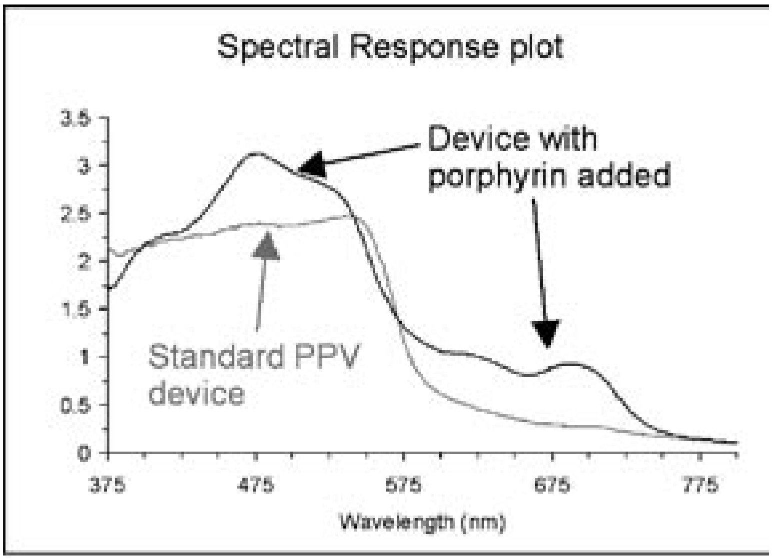


Fig. 11 Spectral response plots for PPV-fullerene solar cell showing absorption improvement with porphyrin.

Notably, in collaboration with Dr Dastoor and chemists at the University of Sydney (Dastoor et al. 2004), we have also recently demonstrated a significant improvement in light harvesting following the addition of porphyrins to PPV-fullerene solar cells (Figure 11) in an Australian Research Council-funded Discovery Project designed to study the effect that different combinations of conducting polymer materials and dyes have upon the performance of polymeric solar cells. Although the introduction of the porphyrin improves the generation of short circuit current across the spectrum (Figure 11) there is no increase in cell efficiency. Further studies are under way to understand this and improve the cell efficiencies.

TOWARDS NANOSTRUCTURED DEVICES

It is now generally accepted that the ideal organic solar cell requires an ordered structure at the nanoscale. The ideal organic photoactive electrode might be made up of polymer nanofibres up to 300 nm long but no more than 20 nm in diameter, so that the charges generated in the polymer have a maximum diffusion length of 10 nm (Coakley et al. 2005). Consequently, we have been investigating a number of ways to achieve this, and present two examples here.

Electrospinning nanofibres

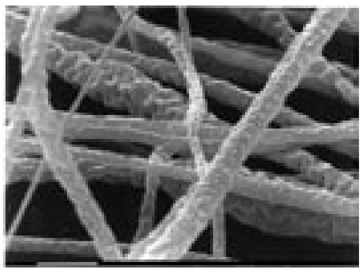


Fig. 12 Electrospun fibres of poly(3-octylthiophene).

In collaboration with Professor Alan MacDiarmid at the University of Pennsylvania we have been developing an electrospinning method to produce conducting polymer nanofibres of soluble and insoluble conducting polymers (Belcher et al. 2004). While mats of CP nanofibres can be readily obtained (Figure 12), the real challenge in this work is the ordering of the nanofibres on electrodes for device construction.

Carbon nanotube–based electrodes

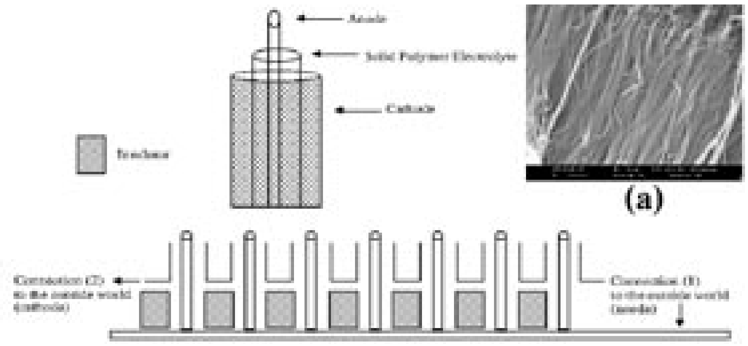


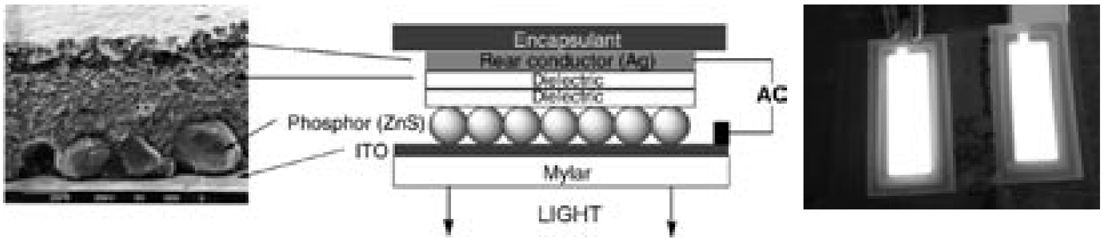
Fig. 13 Cartoon of "shag-pile" electrochemical cell SEM of carbon nanotubes array (a).

Carbon nanotubes are nanometre-sized tubes of rolled-up graphite sheets. Although their discovery is attributed to Electron Microscopist Sumio Iijima in 1991, there were reports of the discovery of hair-like filaments of carbon as far back as 1889, including a report in 1978 by Peter Wiles and John Abrahamson of the University of Canterbury (Wiles & Abrahamson 1978). Although, like the polymer nanofibres, these micron long nanotubes typically form entangled films on electrodes, more recently ordered "wheat fields" of nanotubes of defined length have been grown on silicon and transferred to gold electrodes (Figure 13a). This has raised the possibility of forming "shag-pile" electrochemical cell arrays (Figure 13), which could be used as photovoltaic electrodes. We are currently working with Professor Wallace (University of Wollongong) to achieve this.

Electroluminescent devices

While the widespread use of solar cells would dramatically impact on global energy usage, the other use of technologies such as low-wattage light emitting diodes for domestic lighting could also have a profound impact (D'Andrade & Forrest 2004). This has been highlighted by Dr Dave Irvine-Halliday, a 2002 Rolex Laureate of the Rolex Awards for Enterprise (http://www.rolexawards.com/awards/process/index.html). Irvine-Halliday, a Canadian engineer, who has developed cheap lighting for Third World countries using 2-watt white LCDs says "Lighting up to four million homes with 25-watt incandescent bulbs would require a 100-megawatt power station; with 8-watt compact fluorescent bulbs, 32 megawatts would be needed. But 2-watt white LEDs could light Nepal with just 8 megawatts. Any power station not built is a good power station".

A major contribution to lowering the energy consumption of lighting could result from technology being developed by a Christchurch company, Screen Sign Arts (SSA) Limited. SSA is one of the leading producers of animated electroluminescent displays globally. These lamps comprise ZnS and barium titanate layers screen-printed onto indium tin oxide–coated mylar and coated with a silver electrode (Figure 14). As can be seen in Figure 14a, the ZnS particles are typically 20 µm. The use of ZnS nanoparticles could allow a lower turn-on voltage to be used (typically 100 V AC) and we are pursuing this in collaboration with Professor Doug MacFarlane at Monash University. In addition, the typical electroluminescent emission from ZnS is blue green so a pink fluorescent dye is mixed with the phosphor to give white light emission (Figure 14c). However, the pink dye bleaches rapidly when the lamps are under load in sunlight. A solution to this problem would allow widespread internal and external usage of low power animated displays, replacing current static signage with considerable power saving. Investigations into a range of dyes and lamp structures are under way in association with Associate Professor Keith Gordon at the University of Otago.



(a) (b) (c)

Fig. 14 SEM of electroluminescent lamp (a); cartoon of electroluminescent lamp (b); photograph of screen printed electroluminescent lamps (c).

ARTIFICIAL PHOTOSYNTHESIS REVISITED

As has been discussed above, Nature has created exquisite photosynthetic nanomachinery for the harvesting and utilisation of sunlight. Advances in protein chemistry and molecular biology mean that aspects of this can be replicated in the laboratory. Professor Les Dutton at the University of Pennsylvania has developed methodology for the facile production of de novo synthetic protein helices (maquettes) of nanodimensions (Robertson et al 1994; Discher et al. 2003). Their physiochemical properties can be controlled such that they can be assembled on surfaces such as gold or titanium dioxide (Chen at el. 2002; Topoglidis et al. 2003). Thus, protein maquettes provide a unique platform on which to build a light harvesting reaction centre mimic. We are collaborating with Professor Dutton, funded by a Marsden grant, in the introduction of porphyrin arrays into maquettes. The resulting synthetic light-harvesting maquette has the potential to truly mimic the energy transfer process in LH2 (Figure 3), affording the possibility of carrying out light–driven chemistry within the maquette. Currently, work is proceeding to introduce simple porphyrins into the peptide maquettes..

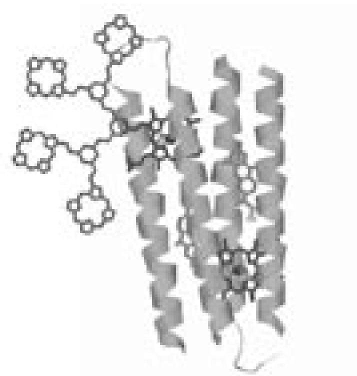


Fig. 15 A synthetic photosynthesis reaction centre.

CONCLUSION

There is increasing concern worldwide about the need to replace fossil fuel consumption with sustainable energy production. A major contribution to this should be the conversion of sunlight to electricity using photovoltaic devices. Despite 50 years of research into silicon PV devices, they are still not highly efficient, cost-effective, and adaptable for a variety of uses, some of the attributes of the ideal PV device. Alternative PV technology such as the PEC nanocrystalline titanium dioxide "Grätzel" cell and organic solar cells could fulfil many of the ideal PV device requirements.

In collaborative research programmes at the Nanomaterials Research Centre at Massey University, we have shown that we can mimic the light-harvesting function of chlorophyll using artificial porphyrins, creating extremely promising photovoltaic materials for Grätzel or polymeric-based solar cells. We have also been successfully developing electrode materials for incorporation into solar cells or electroluminescent devices.

The development of alternative PV technology is particularly challenging and requires multidisciplinary research programmes. After eight years of publicly funded research at Massey University and a number of national and international collaborations, we have produced materials that give world-class PEC and organic solar cell results, and make a significant contribution to the understanding and development of sustainable energy technology. While there is a considerable way to go before commercially viable PV technology can be realised from these developments, there are considerable current benefits to New Zealand from maintaining our involvement in research and development in this area of sustainable energy technology, and future environmental, social and economic benefits from any resulting technology development.

Acknowledgements

The work described in this paper is the result of the hard work of the many talented and creative researchers that currently work or formerly worked in the Nanomaterials Research Centre at Massey University. In particular, I would like to thank my current collaborators Associate Professors Keith Gordon and Ken Jolley, former collaborators Dr Tony Burrell, Dr Gavin Collis and Dr Warwick Belcher, and current NRC researchers Dr Wayne Campbell, Dr Klaudia Wagner, Dr Pawel Wagner, Dr Sanjeev Gambhir, Dr Daina Grant, Ms Amy Ballantyne, Mr Fabio Lodato, Ms Yvonne Ting, and Ms Shannon Bullock. In addition, I am indebted to our international collaborators Professor Gordon Wallace, Dr Paul Dastoor, Professor Michael Grätzel, Professor Les Dutton and Professor Alan MacDiarmid and their researchers.

I am also indebted to the New Zealand taxpayers who fund this research through the Foundation for Research, Science and Technology (MAUX0202: Advanced Materials for Energy Technology Development, MAUX0014: Artificial Photosynthesis Using Porphyrin Arrays, MAUX9913 and MAUX0221: Designer Intelligent Materials), The Royal Society of New Zealand Marsden Fund (04-MAU-110 Artificial Photosynthesis: Mimicking Light Harvesting) and the MacDiarmid Institute for Advanced Materials and Nanotechnology. I hope that this paper will convince some of those taxpayers that the funding of research on New Materials for Sustainable Energy Conversion is well worthwhile.

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Entering the renewable energy era—back to the future

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ABSTRACT

The scientific evidence is compelling that climate change has begun as a result of anthropogenic activities. The Kyoto Protocol has entered into international law and New Zealand's obligation to return to 1990 greenhouse gas emission levels by 2008 to 2012 on average will be challenging to meet. In a carbon-constrained world of the future, renewable energy systems will have an increasing role to play, both nationally and to help meet the rapidly growing global energy demand anticipated over the next few decades. This will be the situation in spite of wide-ranging energy management and energy-efficient initiatives and the uptake of lower energy-consuming technologies. There are three related energy supply paradigm shifts occurring: a) the move towards a hydrogen economy linked with the development of fuel cells for both stationary and vehicle applications; b) the biological and physical sequestration of carbon; and c) the trend towards distributed energy to give security of supply. Linkages exist between all three and renewable energy has a contribution to make to each.

THE PRESENT STATE OF RENEWABLES

At present renewable energy accounts for approximately 30% of New Zealand's and 15% of the world's primary energy supply. Large hydro and geothermal together with woody biomass for heat and cogeneration, some wind and a little biogas, landfill gas and direct solar energy provide around 125 PJ of national consumer energy (Figure 1). Globally the contribution to the energy mix from renewables mainly consists of traditional biomass for heating and cooking in rural areas (9%), modern biomass combustion (3%) and hydropower (3% of consumer energy or 18% of total electricity generation). Additional hydropower potential exists but most large sites have already been developed, the most recent being the controversial 32GW Three Gorges system in China.

Globally there has been rapid deployment of wind turbines and photovoltaic solar power systems (though in a smaller market) during the past decade. The annual growth rate for both wind and solar currently exceeds 25% per year and, together with an increasing number of modern bioenergy plants, accounts for around 2% of global electricity generation (starting from a very small base in the 1970s).

In New Zealand the National Energy Efficiency and Conservation Strategy aims to reduce energy demand by 20% improvement over business as usual and add 30 PJ of new renewables by 2012 (Figure 1). Good progress is being made with wind and biomass heat growing rapidly, solar water heater demand increasing by 40% per year and biofuels for transport showing good potential in the form of biodiesel (from tallow) and bioethanol (from whey) which together could contribute around 2PJ per year.

Renewable energy sources are widely distributed and have the technical potential to meet the ever increasing demand for electric power, heating, cooling and vehicle transport fuels for the developed world as well as for the 1.6 billion people currently with limited or no access to such energy services. Future energy systems must be both renewable and ecologically sustainable for them to be fully acceptable. Hydropower involving the damming of wild and scenic rivers; bioenergy produced from plantation forests, wastes and energy crops; and solar cells manufactured using heavy metals are all examples of where full life-cycle analyses can show whether this is the situation or not.

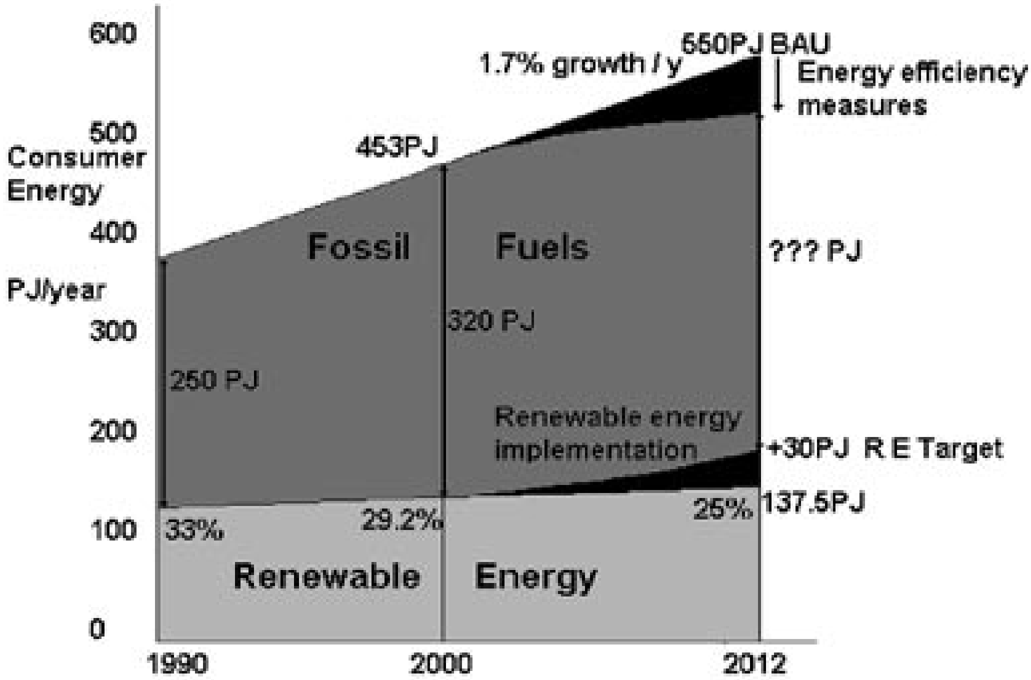

Fig. 1 New Zealand's National Energy Efficiency and Conservation Strategy, first implemented in 2001, aims to slow down the growing energy demand and increase the share of renewable energy by 2012 (see www.eeca.govt.nz).

The use of renewable energy to provide a wide range of energy services (heat, light, comfort, entertainment, information, mobility etc.), including the potential for biomaterials as substitutes for those presently manufactured from petrochemicals (OECD 2003), is an integrating response to a number of global problems. These include equity, development, energy supply security, employment, and climate change mitigation.

Already a public shift is evident in many OECD countries towards better appreciating the value of cheap and clean energy and its links with security, reliability and the environment. Many countries are experiencing energy supply shortages and price volatility for a variety of reasons including high air-conditioning loads, insufficient investment in new generation capacity, dry years reducing hydropower supplies, downstream effects from other extreme weather events and unpredictable activities in the Middle East. This change in public perception will no doubt continue and result, over time, in more integrated approaches to selecting and implementing energy technologies. This in turn will result in changes to private infrastructure investments, Government policies and energy supply and utilisation issues.

DEVELOPING TRENDS AND OPPORTUNITIES FOR RENEWABLES

The Earth has an abundance of both hydrogen (mostly combined with oxygen as water) and solar energy. It is received continually as radiation with a broad wavelength distribution and the annual energy flux exceeds the current total global annual energy demand by over 10,000 times. Capturing sufficient quantities of solar energy in a direct form (as solar thermal and solar power) as well as in its indirect forms (as wind, biomass, waves and ocean currents) would easily meet the increasing demand for energy. It could also be used to produce the energy carrier hydrogen (by electrolysis or gasification). The ultimate goal should therefore be to provide sufficient, affordable and sustainable energy to meet all the basic demands of a growing world population for food, clean water, comfort, mobility and recreation.

Intermittent energy sources, wind, wave and solar, necessitate combining with some form of energy reserve or store. Other sources such as tidal power and ocean currents are intermittent but reasonably easy to predict whereas biomass, dammed hydros and geothermal heat can be stored until needed, as can hydrogen. Theoretically therefore the global energy demand could be met entirely from renewable energy sources when used in a sustainable manner.

Hydrogen is being promoted as a technical solution to mitigate for climate change. Large investments in R & D are being made by the automobile industry, fuel cell developers and governments (US$1.7 billion for 5 years in the USA alone) (IEA 2003). Fuel cells appear to be a promising combined heat and electric power source and as part of a rapidly evolving interest in distributed energy systems. The key question often asked is "Where is all the hydrogen going to come from?" The three leading contenders are biomass; electrolysis using renewable energy sources; or fossil fuels, particularly coal, linked with carbon sequestration (IEA/OPEC 2004).

The coal industry is particularly keen to pursue this latter option as without it, the threat of climate change and the rapid developments in carbon trading may cause its future stagnation. Current predictions are that the electricity price from coal-fired power stations will more than double as a result of the added cost of carbon dioxide capture, transport and permanent storage in saline aquifers, disused mines etc. The forest industry is also investigating the benefits from biological carbon sinks.

Growing concerns at future security of energy supply, for whatever reasons, are driving the trend towards distributed energy (IEA 2004). Indeed there may be no necessity to construct large-scale, nuclear, hydro, combined cycle gas or coal-fired power stations in the future if the costs of renewable energy systems and hydrogen production can be significantly reduced. This could be achieved by increased learning experiences from developing small-scale projects and replicating them (Sims 2002), and by mass production of small heat and power generators (such as the commercially available Whispergen Stirling engine-based system). Additional costs to be imposed as a carbon charge on fossil fuels when releasing carbon dioxide into the atmosphere will also help.

It can be assumed that at some stage after 2030 sufficient renewable energy capacity will have been installed in many countries such that during off-peak periods when normal electricity loads are low, hydrogen will be produced by electrolysis and stored for future use in fuel cells. These will include both stationary applications to provide heating, cooling and electricity for the comfort of, and use by, occupants of commercial buildings and industry as well as in vehicle applications. Up until this period the hydrogen industry will have been developed using hydrogen from various large-scale plants, particularly using coal sometimes linked with carbon sequestration. Once renewable energy technologies have progressed further, hydrogen production on a distributed basis will be the preferred option which, if stored economically, could also be used to overcome the intermittency problems of some renewables.

LOOKING "BACK TO THE FUTURE" FOR RENEWABLES FROM 2030

Since the year 2005 government policies in most OECD countries were developed to further encourage the uptake of renewable energy during this 25 year period. Initial targets from the first decade of the century now appear modest relative to those now in place to meet international obligations to significantly reduce fossil fuel use within the fourth commitment period of the Kyoto Protocol to which all nations have now signed. Most multi-national companies have established new divisions relating to sustainable energy systems as the business opportunities, poorly understood 25 years ago, are now clearly apparent. The revenue obtained from carbon trading is being largely reinvested into sustainable energy systems and other greenhouse gas mitigation options.

Capacity building has been achieved in most countries as renewable energy has become the energy supply of choice for the majority of customers. This has created a wide range of local employment opportunities in this well-respected new industry. Precise control of numerous small to medium generation plants by remote access has been successfully achieved over the internet such that when used by line companies in association with novel energy storage techniques, several nations have achieved over 30% of their total electricity supply coming from embedded generation using community-owned, small to medium renewable energy power systems.

Integration of the harvesting of crop residues for bioenergy feedstocks as co-products with traditional food and fibre products has been made possible by the development of sustainable agricultural systems, GIS-based precision farming techniques, and the efficient recycling of nutrients. Wind farms have moved off-shore with individual turbines over 10 MW_e output being the standard design. These wind farms have been developed in association with wave power devices and ocean current turbines where feasible so that the costly grid infrastructure to bring the power to the shore is shared.

Stationary fuel cells around the 1–5 MW scale are becoming competitive when installed in commercial buildings previously dependent on imported natural gas and electricity for lighting, heating, cooling etc. By regulation, all new buildings in OECD countries have to be passive solar designs and have at least 50% of their energy produced within the building by incorporating renewable energy conversion devices unobtrusively into the structure. The transition to a decarbonised, renewable energy-powered world from the earlier fossil fuel dependent global economy is being further driven by the demand for high quality and reliable uninterruptible energy supply systems since, for a growing number of businesses, even a momentary outage is crippling. Such businesses seek power supply solutions that rely less on centralised power production and access to the grid and more on in-house, privately owned systems. Even so the transition remains in its early stages.

The IEA World Energy Outlook “reference scenario” (IEA, 2002), took into account all previously adopted relevant government policies and measures, and anticipated modest increases for renewables over time (Table 1). However, by 2030 the renewable energy market share has in fact increased by a factor of 10 since 2005, though fossil fuels continue to dominate. As a result carbon emissions continue to rise; high capital investment in infrastructure is needed to meet increasing demand; inequitable access to energy for the growing populations in developing countries continues; remaining fossil fuel supplies remain insecure and environmental damage is a growing concern. It has now become evident to society that to increase the rate of transition to a more sustainable renewable energy and hydrogen-based economy, far stronger government policies and international agreements will be needed in future.

Table 1 Future primary energy supply from renewable energy by region including traditional biomass (Mtoe) (IEA 2002).

	2000	2010	2020	2030
World	**1370**	**1596**	**1808**	**2019**
OECD	**328**	**408**	**497**	**609**
Europe	123	157	197	241
North America	172	209	250	307
Pacific	32	42	51	61
Economies in transition	**41**	**49**	**66**	**81**
Developing countries	**1002**	**1138**	**1246**	**1330**
China	232	245	255	256
East Asia	128	155	169	179
South Asia	250	283	305	317
Latin America	128	149	179	208
Middle East	2	3	4	5
Africa	260	304	333	364

HEADING TOWARDS THE END OF THE 21ST CENTURY AFTER 2050

Since 2050 no more large power stations (fuelled by hydro, nuclear or fossil fuels) have been built as the diminishing global annual increase in grid-connected electricity demand has been met more cheaply from efficient and reliable small to medium distributed generation systems (Lovins *et al.,* 2003). Most rural communities in developing countries now have access to locally produced electricity, hydrogen and transport biofuels having invested in "leapfrog" renewable energy technologies. Medium-scale bioenergy plants have been established in many locations where a suitable sustainably produced biomass supply exists. Even at this scale the carbon dioxide emissions are being captured and physically sequestered nearby in soils and below ground using techniques developed and proven by the agricultural and coal industries in earlier decades.

New, high-yielding, low water-tolerant, energy crop and forest species have been genetically engineered, thoroughly tested and then released for commercial production and subsequent conversion to energy products and biomaterials in multi-product bio-refineries. Surplus land has become available in many sub-tropical regions in Africa, South America and South-East Asia as well as in the old "economies in transition" as a result of higher yielding food and fibre crops now being grown in an efficient and sustainable manner. Bioethanol, biodiesel and hydrogen are also produced and exported to West Europe and North America.

Zero- and low-energy building designs incorporating fuel cells and renewable energy supply systems have replaced existing building stock as it is turned over. The hydrogen for the fuel cells is produced in small solar-powered devices that operate successfully by using new chemical solar collectors that absorb light photons even at low light levels. Together these technologies can now meet 90% of the comfort needs of the building occupants, as well as the energy for all their appliances and vehicles (except in densely populated high latitude regions to where hydrogen is transported). Water recycled from renewable energy-powered waste treatment and desalination plants is abundant and has enabled food, fibre and energy crops to be irrigated in order to maintain yields and meet all the demands of the slowly growing population.

THE FINAL STATE

By 2100, all nations will obtain the major proportion of their electricity, transport and heat demands from a range of renewable energy resources and hydrogen. "Newly developed" countries will have sufficient affordable energy services to meet all the needs of their populations including food and fibre supplies, comfort, industry and clean water for irrigation and drinking. Processed biomass and hydrogen gas will be produced in surplus in tropical and sub-tropical regions and exported to the less sunny regions of the planet. As a result of all these mitigating activities, the atmospheric carbon dioxide level will have nearly stabilised at around 500 ppm.

For any of the above scenarios to be realised there will need to be significantly greater public and private investment in R & D for renewable energy than at present in order to produce improved technology designs, new materials and significant innovative breakthroughs. It will also require exceptional circumstances to provide the ideal driver at just the right time to achieve the transition. The observed increase in extreme weather events as reported by the World Meteorological Office could be the stimulus.

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