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ENERGY RESEARCH INVESTMENT STRATEGY

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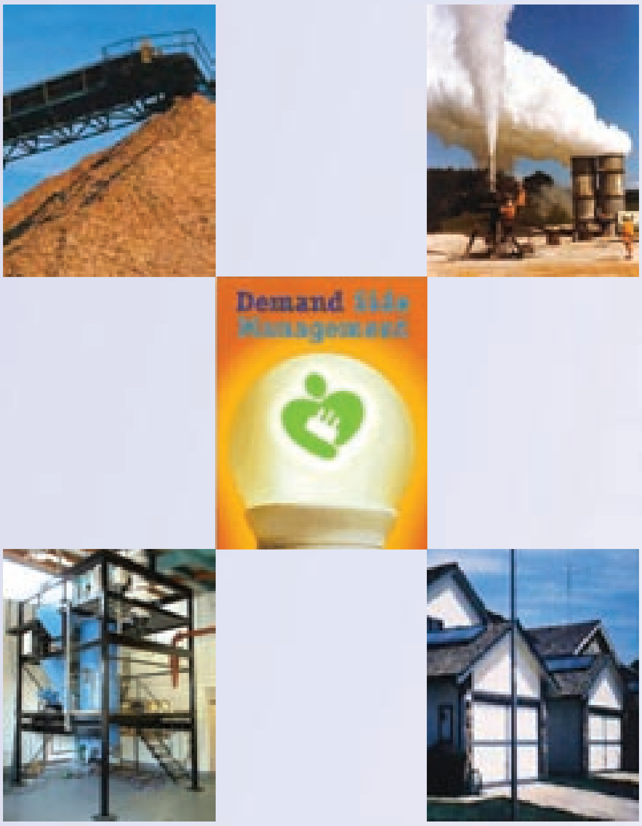

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ENERGY RESEARCH INVESTMENT STRATEGY

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CRL Energy Ltd
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EXECUTIVE SUMMARY

VISION: a research strategy that will secure an energy future that meets New Zealand's aspirations.

This Energy Research Investment Strategy is designed to provide a balanced and forward-looking view of the energy research required to transform New Zealand's energy systems. It is intended as a guide to investment, and to direct research toward that which will provide efficient and effective use of New Zealand's limited research resources.

This strategy covers all aspects of energy research. It assesses the drivers that effect change and those which will result in a sustainable energy future. It is a culmination of information and ideas provided by over 60 experts, representing various organisations and individuals in the energy sector, to provide a vision of the options available to New Zealand.

A significant contributor to this work was information gained from a workshop held in September 2005. This workshop identified the following four energy scenarios, the combination of which could describe almost any future energy scenarios:

- **'primary industry-led growth'** – describing an increase in energy consumption until it is constrained by energy availability and price, and requiring advances in energy-related technologies to improve upon;
- **'energy conservation'** – describing the transition to an economy with zero carbon emissions and largely based on renewable energy, and requiring behavioural and societal changes;
- **'energy security'** – describing the transition to high self-sufficiency in energy and other commodity production, with an emphasis on maximising the use of indigenous primary resources, and requiring technology and New Zealand regulatory changes;
- **'economic transformation'** – describing decoupling the traditional link between energy demand and GDP, and requiring a change to our industrial base.

Each individual energy scenario raises a number of inherent tensions and challenges – for example, the possible conflict between environmental protection and absolute security of supply. Each would require a degree of change -technological, economic, societal or behavioural – but the nature and extent of change varies according to the final mix of elements, and in itself warrants significant on-going investment and research.

Key areas identified as research priorities include:

- changing energy use patterns, e.g.:
  - adoption of new technologies and transport alternatives;
  - understanding how market developments drive energy-efficient behaviour.
- modelling to aid transformation of the energy infrastructure into a more efficient and distributed system;
- identification of the optimal balance of resource use and environmental implications;
- investigation of bio-energy, e.g.:
  - economic production of feedstocks;
  - bio-refinery products; and
  - development of transport biofuels.
- consideration of high-efficiency/low-impact conversion technologies, including low-carbon transport fuels;
- assessment of the potential and characteristics of New Zealand's key energy resources; and
- investigation of the New Zealand potential for carbon capture and sequestration.

These key areas were further divided into 13 specific energy research fields. Table 1 lists the mean required importance of research for each of the energy research field with respect to the energy scenarios. It is a summary of Table 3 in the main report which was derived from discussions during the ERIS workshop held in September 2005, the analyses provided by experts in each area, and subsequent feedback from the energy industry.

The significance of energy modelling (which was not considered to be a specific energy-related research field, by its nature) is also provided.

Table 1: Mean Results of an Evaluation of Required Importance of Research

Energy Research Field	**Primary Industry –led Growth**	**Energy Security**	**Economic Transformation**	**Energy Conservation**
Energy Modelling	++	++	+++	++
Demand Side: Residential	++	++	+++	++
Demand Side: Industrial	++	++	+++	++
Demand side: Technologies	+	++	+++	+++
Infrastructure	++	++	+++	+
Bio Energy	+++	+++	+++	+++
Solar	++	++	++	+++
Wind Energy	++	++	+++	++
Ocean and Hydro	++	++	++	++
Geothermal	+++	+++	++	++
Hydrogen	+++	++	+++	+
Carbon Capture & Storage	+++	++	+++	+
Coal	+++	+++	++	+
Petroleum & Gas	+++	++	+	+

Legend: Required importance of research:
+++ - High
++ - Medium
+ - Low

Note that this document does not intend to prescribe a pathway for New Zealand's energy future. It is a guide to understanding the options and issues that are facing New Zealand and the research required to achieve any of the possible energy futures. The strategy is a living document that will change and adjust as different technologies and pressures have an effect as progress is made.

1. INTRODUCTION

In the past few years, there has been a growing awareness both in New Zealand and internationally that given the current patterns of energy use, the sources from which energy is derived will eventually be depleted to a level where it is neither economic nor environmentally wise to continue using them. The signs that these limits are being approached are becoming more frequent and persistent with rapidly rising oil prices, more effort required to access, extract or harness resources and the general acceptance that human activity is having a measurable effect on the climate.

As an added pressure on New Zealand's energy systems, international developments are having an effect on New Zealand both in terms of fluctuating prices for imported energy and in growing awareness that our energy use is vulnerable to international events. Energy security has become a major issue for industry, government, and the public both here and overseas.

The way we use energy affects everything we do and hope to do. A change in the energy systems will therefore fundamentally change the way in which New Zealand society operates. Changes in the energy system could be by choice, or as a consequence of refraining from choosing. It is critical that we all (industry, government and the research community), as much as possible, agree on what those changes should be, how fast they need to happen and how best to bring them about.

As a stepping stone on the path towards developing a more sustainable and secure energy future for New Zealand, this Energy Research Investment Strategy has been designed to provide a balanced and forward-looking view of the energy research that will be required to underpin the future transitions of New Zealand's energy systems. This document seeks to guide investment in areas of research, to direct research in a way that will make efficient and effective use of New Zealand's limited research resources and which will ensure these are directed toward achieving a more sustainable future and the flexibility to meet unforeseen events. This document is expected to be dynamic and thus will change and adjust as different technologies and pressures come into play in the future.

As it is a product of industry and the energy research community, this research strategy is intended to complement the various strategies that have been and are being produced by government agencies and others. By providing a clear direction on what energy research is worthwhile investing in, it is hoped that the added confidence generated will in turn encourage investment by industry and government. Clear direction, coordination and certainty will also create an environment where high-quality and highly relevant research can flourish.

This Energy Research Investment Strategy considers all aspects of research from fundamental research to the demonstration of new energy systems, the examination of the movers that cause people to make the energy choices they do and the impacts that any given energy solution will have.

1.1 Who Will Use This Document?

This document is designed to fulfil multiple purposes and as such different parts of it will interest different readers. Some of these purposes include:

Strategic Planning
This report has been designed to provide a useful summary of the strategic priority research areas as seen by industry and researchers in the energy research industry. The descriptions of scenarios developed contain an overview of the research priorities for each that will allow a reader to pick and choose elements of the different scenarios that may emphasise a particular strategic effect that is desired. For instance, when designing a research strategy for a particular purpose, the designer may wish to pull some ideas from the Primary Industry-Led Growth scenario but may also want to add some aspects of the Energy Security scenario.

Research into Particular Fields
A series of concise summaries of energy research undertaken both within New Zealand and overseas is presented; each summary has been written by specialists working within their area of expertise. This section is intended to inform and to indicate the status of research in a particular field, where it might go in the future and what projects should be considered for funding.

Other Strategic Documents
The Energy Research Investment Strategy is not intended to duplicate the work of other research strategies for specific areas and sectors; rather it is intended to run in parallel to these other strategies. As it brings together the views of the researchers working in energy research and in the energy industry, it provides another point of view that will help round out the range of priority options.

The strategies which have been considered in the development of this document include:

- *Sustainable Energy – Creating a Sustainable Energy System*, Ministry of Economic Development (MED), (2004);
- *Land Transport Research Needs in New Zealand*, Ministry of Transport (MoT);
- *A Sustainable Energy Future for New Zealand by 2050 – A Business View*, the New Zealand Business Council for Sustainable Development (NZBCSD); and
- *The National Energy Efficiency and Conservation Strategy*, Energy Efficiency and Conservation Authority (EECA), (2001).

Other energy and energy research strategies either existing or in development include:

- *The National Energy Strategy*, MED;
- *The Energy Roadmap*, Ministry of Research Science and Technology (MoRST);
- *2020 Energy Opportunities*, the Royal Society of New Zealand; and
- *The Sustainable Energy Research Priorities* Document, EECA.

1.2 Where To From Here?

Research, technology, societal needs and drivers are dynamic processes that can develop in unexpected ways. For this reason, this document is the start of an on-going process of development, for if it is to be useful it must in time cater for the new possibilities yielded by current research and allow for changes in the pressure points arising from both external factors and internal factors. The optimum energy solution for New Zealand will be unique to New Zealand.

The summary of current energy research and research potential presented here is intended to paint a picture of the possibilities and trade-offs open to New Zealand. We believe that there are compelling reasons to take a co-ordinated approach to energy research and development and that such an approach is more likely to yield the best possible result for New Zealand than is the piecemeal approach which has prevailed since the economic reforms of the 1980s. Planning for energy research and development must be iterative, for once current research is completed; new constraints and possibilities will have emerged. In conclusion, this document provides a useful and useable expert view on strategic research topics which, if pursued – and an adequate investment made – will help New Zealand develop balanced and informed energy policy, build research and technology capability, allow informed assessment of New Zealand's future energy options, and confirm future sources of energy supply.

2. VISION

'A research strategy that will secure an energy future that meets New Zealand's aspirations.'

Through a programme of research which will lead to efficient and optimum use of our extensive and diverse energy resources while respecting the associated environmental constraints, we will achieve a future that enhances our quality of life, and ensures our environment is protected.

2.1 Outcomes

The envisaged outcomes include:

- ensuring that all users, from major industry to domestic users, get the maximum benefit from New Zealand's energy by promoting its efficient and optimum use in an environmentally considerate manner;
- an optimised infrastructure for delivering the energy to users efficiently and with the lowest possible impact (in particular for electricity, gas and transport fuels);
- low or "zero" emissions supply and conversion technologies of appropriate scale to produce electricity, heat and transport fuels for New Zealand's industrial and domestic users; and
- evaluating and developing New Zealand's extensive energy resources, energy efficiency opportunities, and reducing our need to import energy while ensuring that our actions do not compromise the future ability of the resources and environment to function successfully.

We will achieve these outcomes by a national research programme which will:

- increase research capability;
- bring in young talent, and enhance public understanding of energy issues;
- weigh up the balance between risk and benefits;
- develop intellectual property (IP);
- encourage international collaboration;
- encourage and support industry/government collaboration;
- be strategically aligned to national goals;
- meet the needs of New Zealand;
- produce measurable benefits;
- be responsible and appropriate; and
- be balanced and considerate of all effects and impacts of the programme on society, the environment and the economy.

This document does not intend to prescribe a pathway for New Zealand's energy future. It is a guide to understanding the options and issues that are facing New Zealand and the research required to achieve any of the possible energy futures. This strategy is a living document that will change and adjust as different technologies and pressures have an effect as progress is made.

2.1 Overarching Themes

Underlying this vision and envisaged outcomes is an understanding that some degree of change is required from all parts of the economy. The type of change may be technological, economic, societal or behavioural. The extent to which this change may occur under different energy futures will be driven largely by some overarching themes that may not only influence the ease of change, but also may impose limitations on what can be done. As a result, the importance of each of the drivers will vary for each of the four scenarios assessed in the next section and will determine the resulting research priorities.

Key Drivers or Overarching Themes

Education and Behaviour
Energy is used by people for a vast range of activities. People and their behaviour are therefore keys to the success of any change in the way energy is produced and used. In developing energy research programmes and priorities, consideration of individual and societal behaviour is essential. Education and demonstration will be a major part of any successful, far-reaching energy research programme.

Global Demand
Global demand for energy services is driven by development (as currently in China and India). One third of the world's population does not have access to commercial energy. New Zealand could help address energy poverty through the development of energy efficient or renewable energy technologies and techniques and by facilitating the adoption of these technologies in the developing world.

Markets
Market drivers are important for the implementation of any change as they can either help or hinder the transition. Any energy research priority development must take into consideration the roles that the market plays so that the chances of success of a particular energy solution can be maximised.

Energy infrastructure
Energy use relies on energy infrastructure to get it to the points of end use. In developing energy systems for the future, the infrastructure must also adapt in parallel to ensure that the maximum potential of a particular energy system is achieved. In developing energy research strategies, consideration must be given to the infrastructure that is present now and what modifications or new infrastructure will be required in the future to meet the different needs and performance expectations that might arise.

Finding the balance
There is increasing competition for access to resources between energy production, food production, recreation, environmental protection and many other activities. When developing of energy research priorities, it is essential that the balance is considered so that the future developments enabled by research ensure that the resource use is optimised to provide for the maximum number of uses without adverse effects on the resource or other legitimate users.

Climate change

Climate change is now recognised as a major global issue and there is general acceptance that it is at least partly driven by anthropogenic release of greenhouse gases, including carbon dioxide and methane. New Zealand will need to play its part by reducing its emissions to a minimum and participating in global efforts to stabilise levels of environmental greenhouse gases. The greater the increase in energy use, the greater the challenge to stabilise emissions. The greenhouse gas emissions from the transport sector will be especially challenging. If we cannot stabilise emissions we will expose ourselves to the international price for emissions credits and the potentially greater costs associated with the effects of climate change on land use and damage by extreme weather events.

Energy resources

New Zealand is better off than many countries, for we have a potential wealth of energy resources of all types. The optimum energy use pattern and the optimum research path to help reach it will be dependent on an adequate understanding of the full range of energy resources available, their sustainability and the impacts exploitation will have on the natural environment.

Global energy supplies

There is a constrained oil supply (through peak oil being reached or supply disruption due to international destabilisation) and constrained natural gas supply (through the limits of economically available gas supply being reached). These factors, together with increasing energy demand from growing economies, including developing countries such as China and India, will lead to increasing pressure on energy supplies and corresponding increase in prices.

New Zealand has a choice as to whether it exposes itself to world energy prices or develops its own energy resources. A comprehensive research programme will help determine where the best path lies, and will consider the economic, social and environmental risks associated with increasing international demand pressure on dwindling fossil fuel resources.

3. THE ENERGY SCENARIOS

In the development of this strategy, four different futures were considered in an effort to create a framework for considering the likely future. The four scenarios were plausible but extreme and as such unlikely to happen as described. They describe a region of possible futures that bound a likely outcome. The four futures considered were: ‘primary industry-led growth’; ‘energy security’; ‘economic transformation’; and ‘energy conservation’. These scenarios were based on three studies by various organisations.

Table 2: Scenarios Used to Inform Workshop Discussions

Study Title	Primary Industry-Led Growth	Energy Security	Economic Transformation	Energy Conservation
NZBCSD Sustainable Energy by 2050: A Business View	Growth	Shielded	Transformation	Conservation
Massey University Future Energy Scenarios for New Zealand	A1: Business as Usual: Low Carbon price	C: Closed Conflict	A1 Business as Usual: High Carbon Price B1 Sustainability: 1990 Emissions Target.	B3: Sustainability: Fossil Fuel Free
Parliamentary Commissioner for the Environment	Fuelling the Future		Sparking New Designs	

The primary industry-led growth and energy security scenarios are essentially business-as-usual scenarios. The growth scenario would apply where world energy prices are affordable and energy availability is relatively unconstrained whereas the energy security scenario would apply during times of high prices and energy shortages.

The economic transformation and conservation scenarios will only apply if a considerable national effort has been made to change the way New Zealand produces and uses its energy. Renewable energy will form a much higher proportion of the total energy available. The economic transformation scenario places emphasis on wealth creation through increased use of sustainable energy at reasonable prices whereas the conservation scenario focuses on reducing overall energy use and would probably be associated with a high energy cost environment.

Each scenario would require a different energy research effort. At the broadest scale, the primary industry-led growth scenario will mainly require advances in energy technologies, while the economic transformation scenario will require changes to our industrial base, and the energy conservation scenario will require behavioural and societal changes. The energy security scenario will require changes in technology as well as changes to New Zealand’s regulatory environment.

All are underpinned by specific projections of future energy use. The diagrams which follow show selected projections originally developed for the Parliamentary Commissioner for the Environment and the NZBCSD scenarios.

Figure 1: Demand for Energy Services and Electricity Use from PCE Scenarios[1]

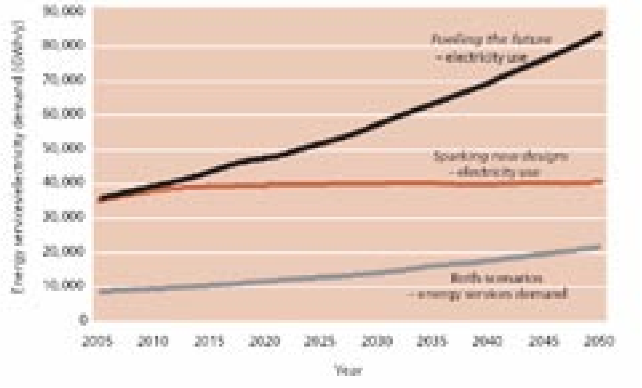


Figure 2: Energy vs. GDP for the NZBCSD Scenarios 2005-2050[2]

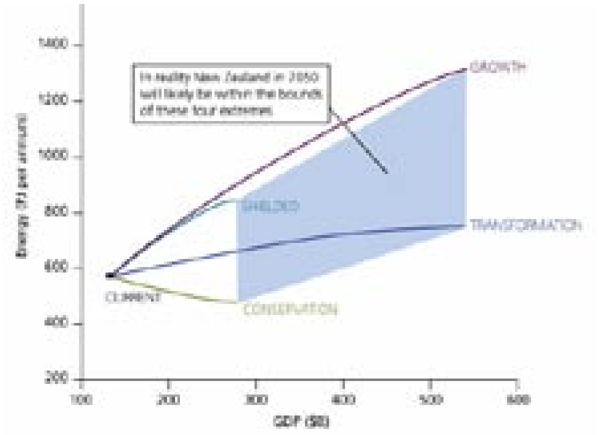
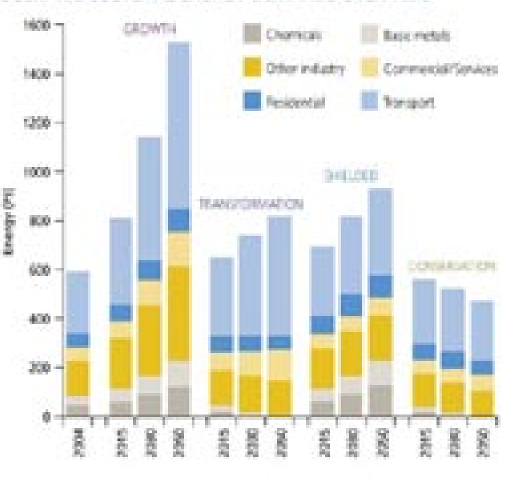


Figure 3: Sectoral Energy Demands for the NZBCSD Scenarios 2005-2050[3]



The following sections (3.1 to 3.4) summarise discussions held at breakout sessions at the Energy Research Investment Strategy Workshop (held September 2006). Four separate groups considered the research needs of the four future scenarios for New Zealand through to 2050. The results of these sessions – together with assessments by the technology experts of research needs in their areas under each of the four scenarios as well as subsequent feedback from the energy industry are collated in Table 3. Table 3 is then summarised and the results are presented in Table 1 of the Executive Summary.

3.1 Primary Industry-Led Growth Scenario

Facilitator at Workshop: Catherine Beard

The Primary Industry-Led Growth scenario is based on the 'Growth' scenario provided in *Sustainable Energy by 2050: A Business View*, (NZBCSD, 2005) and also takes into account aspects of the Massey University's *Future Energy Scenarios for New Zealand* 'A1: Business as Usual: Low Carbon Price Scenario' and the Parliamentary Commissioner for the Environment's 'Fuelling the Future' scenario.

The following description was adopted from *Sustainable Energy by 2050: A Business View,* NZBCSD, 2005.

NZBCSD Energy 2050 GROWTH

Competitive advantage in energy prices

New Zealand is prosperous, benefiting from the open flow of trade and investment globally. The economy is based on energy-intensive processing of natural resources, based on competitively priced energy from indigenous gas and coal. New Zealanders enjoy high standards of living with a high degree of mobility. The economy is market focused, with a light-handed regulatory approach. Energy demand is very high.
Bountiful supply makes technological change less urgent. Improvements in energy efficiency are swamped by increased demand from higher living standards.

However, with state encouragement of R&D, investment in biofuels, hydrogen and CCS[4] allows the economy to transition smoothly to more sustainable energy options in the face of declining oil supply. New Zealand meets its climate change obligations through relatively benign environmental pricing instruments that provide assistance to renewable energies.

Sustainability criteria assessment

In the Growth scenario, affordability of energy is paramount to maintain continued high economic growth. The other two criteria have a role but the priorities change over time. Early expansion of coal generation in advance of viable CO_2 sequestration raises environmental protection and general acceptability issues, particularly if this is detrimental to continued renewables development.

Security of supply could become a risk due to the need to deliver a significant increase in energy demand whilst relying on one or two key fuels. Environmental protection becomes a key risk if there is a strong dependence placed on sequestration technology to stabilise CO_2 emissions which may not materialise.

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[1] *Future Currents: Electricity Scenarios for New Zealand 2005-2050*, Parliamentary Commissioner for the Environment, 2005.

[2] *Sustainable Energy by 2050: A Business View*, NZBCSD, 2005.

[3] *Sustainable Energy by 2050: A Business View*, NZBCSD, 2005.

[4] CCS: carbon capture and storage

Scenario Requirements

For an economy based on the energy-intensive processing of natural resources, we need competitively priced energy, so the key challenge for this scenario will be creating security of energy supply at competitive prices. A growing economy will lead to increasing energy consumption and growth will only be constrained by energy availability and price. Part of what makes up the price element will be adequacy of supply and infrastructure and whether the environmental externalities are priced, such as a carbon tax on fossil fuels. Assuming there is increasing international pressure to minimise CO_2 emissions, then New Zealand needs to invest in technology or R & D that allows us to use our energy sources as cleanly as possible.

For all scenarios there are a range of technologies that can help to meet energy requirements on both the supply- and the demand-side. This scenario is the more aggressive so will require a greater stretch, inevitably requiring greater emphasis on our coal resource and on the oil and gas prospects of New Zealand's extensive and almost unexplored sedimentary basins. New Zealand has plenty of coal, but will we be able to (or will we want to) use it to support our economic growth? Can it be mined economically, at a cost that is environmentally acceptable? Clean coal technologies are likely to become commercially viable but will always be an added cost on the cost of mining and remediation.

We need to be able to identify the potential roadblocks to growth and then see if research is going to be able to take some of those roadblocks away. For example, for security of supply, major new gas discoveries would help the high growth scenario - then the question is how clean can the gas be?

Roadblocks to high growth that were identified included:

- carbon emissions;
- infrastructure constraints;
- accessibility to resources;
- access to low-cost fuels;
- access to low-cost transport;
- access to new energy technologies.

Research and development efforts should be directed at reducing these barriers to growth. Being an exporting nation that is geographically remote from our markets, New Zealand has to keep energy costs down to stay internationally competitive. If we don't stay internationally competitive our growth will falter.

Research Priorities

The high growth scenario needs numerous solutions. The growth scenario research priorities include investment in research and development on:

- biofuels;
    - seeking low-cost collection;
    - drying;
    - conversion to liquid fuels;
- fossil fuels;
    - new technology for smaller-scale plants for all resources would be suited to New Zealand conditions;
- coal;
    - carbon capture and sequestration (CCS, biological/storage);
    - hot gas clean-up;
    - gasification for New Zealand coal and hydrates;
- oil and gas;
    - resource assessment;
- biomass;
    - thermal heat;
- low-grade heat;
    - assessment of demand;
- wind;
    - integration of wind energy with New Zealand infrastructure;
    - security of supply;
- solar;
    - New Zealand-appropriate systems - industrial, commercial;
    - process heat and passive solar (building design);
    - integration into New Zealand system, demonstration;
    - photovoltaics (PV);
- ocean/hydro (including low-head hydro);
    - Resource assessment;
    - Transfer of technology and adaptation to New Zealand;
- geothermal - resource assessment;
    - Extraction of minerals;
    - 'Cascaded', 'parallel' or more efficient energy use;
- hydrogen;
    - Carbon capture and sequestration (biological/storage);
    - Feedstock;
- distributed generation;
    - Research across all energy sources would be beneficial.

3.2 Energy Security Scenario

Facilitator at Workshop: Robert Tromop

The Energy Security scenario is based on the NZBCSD's *Sustainable Energy by 2050: A Business View*, 'Shielded' scenario and also takes into account aspects of the Massey University's *Future Energy Scenarios for New Zealand* 'C: Closed Conflict' scenario.

The following description was adopted from *Sustainable Energy by 2050: A Business View,* NZBCSD, 2005.

NZBCSD Energy 2050 Shielded

Oil shocks and recessions resulting from high energy prices see the global economy trend toward isolationist markets and trade blocs - free trade loses ground to protectionism. New Zealand's economic growth is lowered. Electricity crises and fuel shortages result in New Zealanders demanding that supply security be the absolute priority shielding the country from international markets. Government has underwritten energy supply and infrastructure but the resulting high taxes hinder economic growth and harm investor confidence, reinforcing the need for more government intervention. However some energy-related investments benefit from higher energy prices. Subsidies are used to attract and retain energy-intensive industries. Government investment in R&D focuses on supply security, diversification of energy supply and substitution of transport fuels.

Sustainability criteria assessment

The Shielded scenario places security of supply as the absolute priority and affordability of energy as highly important. The consequent low priority on many aspects of environmental protection creates a key sustainability risk. Investment in large-scale energy infrastructure is detrimental to the continued development of most renewables. On the positive side, self-sufficiency in transport fuels including biofuels and coal-derived, low-carbon, synthetic fuels (made sustainable with CCS) is hailed as an environmental success story.

Scenario Requirements

The Energy Security scenario is based on developing a New Zealand-centric or isolationist approach to meeting our future energy needs.

New Zealand would develop into a society that is highly self-sufficient in energy and other commodity production with an emphasis on maximising use of indigenous primary resources. Security of supply (in both a long and short term sense) will underpin energy and infrastructure decisions, including probably nationalising the energy supply industries. There is a strong emphasis on energy efficiency, planning and design to reduce the amount of energy used, and making smarter use of energy. Energy conservation and renewable energy become essential planks of this approach, with heavy regulation to ensure demand is minimised and indigenous resources are fully utilised.

Developing New Zealand's geothermal and fossil fuel resources will also become a high priority. Stationary energy requirements can largely be met by renewable energy resources. Despite the adoption of renewable stationary energy by a vast increase in electric rail for both freight and commuting, liquid transport fuels still dominate the 2050 transport energy mix. These factors prompt the development of local industry producing liquid fuels from gas and coal primary energy resources.

Essentially, Energy Security New Zealand means going it alone. Regardless of the economics we will develop all possible demand-side and supply-side options to avoid importing energy resources, and will retain all indigenous energy resources for our own consumption.

Global Issues

The above scenario is predicated on the rejection by New Zealand, along with other nations, of global initiatives to enhance multi-lateral cooperation, liberalise trade and mitigate climate change impacts. This is a wholesale change from current policies for virtually all nations and a serious reduction in international trade in all commodities, not just energy commodities. Major political, social and behavioural change will drive and result from this future. It is reasonable to expect that consumption of imported technologies will be significantly reduced due to lack of availability. This will affect all parts of society including purchases of industrial equipment. To make up for the lower levels of new equipment and materials being imported, local heavy engineering industries and material recycling industries are likely to grow to meet the needs of the country.

Domestic Changes

Economic growth will focus on developing wealth internally, reducing both energy-intensive exports and controlling imports. Social growth and improved life quality will occur through the generation of new jobs and industries to support the local energy sector and an expanded domestic services sector, but constraints on imports will hold back many areas of development. Energy prices will still reflect international prices as the regulations that control accessibility to energy are based on avoiding cost of imported energy resources.

Policy changes will also be required. Rather than markets defining the price quantity mix and inter-fuel competition, nationalised energy industries will determine resource allocations and resultant pricing. The Resource Management Act would be revisited in favour of resource security priorities.

Feast Or Famine: Does New Zealand Find Another Maui?

A key factor in what energy resources are developed is whether we discover and extract another large (or series of medium) gas fields. This will change New Zealand's options but may not change the ultimate outcomes in this fortress scenario. Two sub-scenarios outline the possibilities:

Feast: We find another Maui. The nation may require another take-or-pay contract in order to make extraction viable, given the small-scale domestic market. Given a nationalised energy supply industry and a heavily controlled market, with no export of the gas (directly as LNG or CNG or indirectly as energy-intensive products such as methanol) and regulated use of renewable energy, the gas would probably be used for transport and electricity security. The nation would be reliant on international gas companies for extraction, but would direct all products into the domestic economy regardless of cost.

Famine: We don't find new gas resources at medium to large scale. This forces a high reliance on coal. A significant investment is made in producing synthetic fuels, coal gasification and electricity generation. It can be assumed that energy transformation and end use plants would still need to meet regional air quality requirements and that would be manageable. Despite the rejection of international treaties on climate change, there would still be a need to manage greenhouse gas emissions.

Consumer Energy Products

Electricity continues to grow in the mix of consumer energy products. Consumers continue to develop their existing preference for electricity, this demand is underpinned by adoption of heat pump technologies for space heating, water heating (about 60% of household and commercial sector energy consumption) and low temperature industrial processes.

As mentioned above transport fuels are still largely liquid fuels, based on a mix of bio-fuels, bio-diesels, New Zealand-sourced crude oil and condensate CNG, LPG and synthetic fuels from coal. While other nations may develop some hydrogen transport options, New Zealand's isolationist approach would focus on a lower risk, less high tech, higher return from producing its own synthetic liquid fuels, or possibly, on a niche basis, from higher use of gas as a primary transport fuel.

Matching the focus on energy security with the variability and distributed nature of renewable energy generation should see significant development of the transmission grid to ensure electricity security as well as its basic transmission function. In conjunction with this, the development of regulated, real-time pricing and advanced metering along with demand shedding and energy storage mechanisms will offset the variability of renewable energy.

Research Priorities

The nature of the scenario points to a strong focus on maximising all indigenous resources. This suggests that priority research streams will focus on understanding how consumer behaviour and practice can be managed; ensuring a good understanding of indigenous resource availability; and understanding essential technologies to realise indigenous resources.

High Priority

Those research areas of high priority include:

- research to identify those potential indigenous energy resources which are not yet adequately understood (oil, gas, geothermal, and – to a lesser extent – coal), in order to understand our demand-side and supply-side energy inventories fully;
- determining sustainable depletion limits of all resources;
- research into public behaviour and education to understand how to manage energy use patterns and optimise energy allocations;
- research aimed to maximise the uptake of energy conservation and efficiency and energy conversion technologies in all sectors;
- economic research into both market-based options, subsidies, taxes, and regulatory mechanisms to manage energy use patterns;
- security implications of networks and their development;
- optimisation of energy transformation, and energy value, chains: e.g., distributed wind farms integrated with electric rail system;
- central control of energy industries and systems – generator merit order, modelling, networks, etc;
- development of renewables including marine, solar, bio-energy from feedstock growth, bio-diesel, bio-ethanol fuels, bio-refineries etc in order to maximise indigenous resources.

Watching Brief

Those of 'watching brief' status include the continuous monitoring on potential international projects such as research into hydrogen and carbon capture and storage.

3.3 Economic Transformation Scenario

Facilitator at Workshop: Gerry Carrington. Editor: Tony Clemens

The Economic Transformation scenario is based on the NZBCSD's *Sustainable Energy by 2050: A Business View*, 'Transformation' scenario and also takes into account aspects of the Massey University's *Future Energy Scenarios for New Zealand* 'A1 Business as Usual: High Carbon Price' and 'B1 Sustainability: 1990 Emissions Target Scenarios', and the Parliamentary Commissioner for the Environment's 'Sparking New Designs' scenario.

The following description was adopted from *Sustainable Energy by 2050: A Business View*, NZBCSD, 2005.

NZBCSD Energy 2050 Transformation

Transform economy to reduce energy dependence

Energy prices are high with the full cost of imported energy (e.g. LNG) and environmental externalities flowing into the economy. New Zealand has no competitive advantage but continues to remain prosperous because we have transitioned to a largely service-based economy combined with the production of higher-value products.

Energy-intensive industries have declined, particularly in some regions. While market focused, the Government has encouraged the transition of the economy by assisting extensive R&D and setting stringent energy efficiency and environmental standards. Energy demand has grown, but no longer has a strong link to GDP. This change has been assisted by a radical focus on the way New Zealand's social and transport needs are met. In urban areas, a first-class public transport infrastructure exists but energy savings are more than offset, e.g. by increased international travel driven by personal wealth. Households use less energy and in many cases generate their own, e.g. solar panels. Primary energy supply is diverse and largely renewable, with some fossil fuels where supported by CCS.

Sustainability criteria assessment
The transformation scenario highlights how high energy prices and environmental protection drive the economy away from its previous dependence on energy-intensive industry. Affordability of energy is given a lower priority, made possible by strong international trade along with support to develop non-energy sectors. Security of supply, provided through greater diversity of fuel types, is considered an important priority to avoid oil shocks and electricity crises, but is secondary compared with environmental protection
http://nzbcsd.org.nz/energy2050/content.asp?id=369

Scenario Requirements
A scenario that 'decouples' the traditional link between energy demand and GDP and whose realisation requires maintaining a workable balance between environmental protection and security of supply is clearly faced with a number of inherent tensions and challenges.

The energy infrastructure will change. The short to medium term is characterised by an interactive grid system, greater use of public transport, smart buildings and increased distributed generation. Longer term, a hydrogen infrastructure will become increasingly prominent. In order to avoid costly mistakes associated with stranded infrastructure investments we will need to understand the changes and manage the transition in a cost-effective manner. Improved energy modelling capability will be required both for the infrastructure changes and to identify market drivers underpinning the new system.

A well managed, diverse primary energy supply is a key part of the transformation scenario. Although we will have reduced energy intensity, we will still be using more energy than we presently do. There will be increased renewables in the energy mix and we must ensure we understand our available resources and use the best existing and new technologies to produce energy from them. It is also recognised that renewables alone will be insufficient to meet increased energy demand and the environmentally sustainable use of fossil fuels will also be an important part of the transformation scenario.

As the energy infrastructure changes, so too does the society it underpins. There is a need to understand the complete energy system and to have available the necessary tools for up-skilling a new and increasingly versatile energy sector workforce.

Research Priorities
The high priority transformation scenario research investment areas needed to meet the above challenges include:

- bio energy - optimal use of resource (energy as against biomass product) and implications for land use;
- fossil fuels - best technologies and carbon capture and sequestration;
- marine - identification of new resources, and efficient use of existing developed resources;
- geothermal - identification of new resources, including 'deep geothermal', permeability enhancement, continuing enhancement of production from known fields, secondary recovery for electricity generation, and increased use of geothermal direct heat;
- hydrogen - in partnership with international organisations to ensure progress remains in step with the rest of the world;
- infrastructure - identification of required changes and how to manage them;
- markets - understanding existing and future markets and how markets drive energy demand and utilisation.

3.4 Energy Conservation Scenario

Facilitator at Workshop: Hamish Trolove

The Energy Conservation scenario is based on NZBCSD's *Sustainable Energy by 2050: A Business View* 'Conservation' scenario and also takes into account aspects of the Massey University's *Future Energy Scenarios for New Zealand* 'B3: Sustainability: Fossil Fuel Free' scenario and the Parliamentary Commissioner for the Environment's 'Sparking New Designs' scenario.

The following description was adopted from *Sustainable Energy by 2050: A Business View,* NZBCSD, 2005.

NZBCSD Energy 2050 Conservation
New Zealand has higher energy prices than many of its international competitors because of the high value placed on environmental protection. Greenhouse gas emissions are priced at a high level. New Zealanders accept lower economic growth in favour of a sense of community, care of the environment and a willingness to minimise the energy/material costs of consumerism. Energy-intensive industries decline and primary industries provide low added value. New Zealand achieves its goal of reducing its dependence on fossil fuels from transport by using biofuels from crops and forest residues. The Government drives change through major conservation and energy efficiency policies. Over-investment in energy infrastructure is avoided and people are willing to accept occasional supply constraints.

Sustainability criteria assessment
The Conservation scenario highlights a situation where environmental protection is paramount. Security of supply is given a somewhat lower priority because people are prepared to accept some supply constraints. To meet social obligations, the affordability of energy services for low-income households and small businesses.

The Energy Conservation scenario is based on transitioning to an economy with zero carbon emissions and largely based on renewable energy. New Zealand is likely to develop into a relatively self-sufficient society in terms of both energy and food production with an emphasis on reducing primary energy use through energy efficiency, energy transition efficiency improvements and energy conservation. Despite progress towards this goal, fossil fuels are still likely to be present in the 2050 energy mix.

Economic growth as measured by GDP will have given way to social growth and improved life quality through the generation of new jobs and industries to support the renewable energy sector and an expanded services sector. With high energy prices, there will be a strong emphasis on energy efficiency and good designs to reduce the amount of energy used, and make smarter use of energy.

Major social and behavioural change will be essential for the success of this future.

Scenario Requirements

There are a number of pressures, constraints and influences that must be worked with or resolved in order to reach a low energy mix.

New Zealand already has a working economy with a stock of existing buildings, infrastructure, fleets, and people. A challenge of this scenario will be how to work with the constraints imposed by what we have now and how to adapt them to a more efficient and energy-conservative way while working within their natural product lifetimes.

The major risk for this scenario is the amount of behavioural and societal change required. In order to aid the introduction of the changes, education of the public will be required not only to help them understand energy issues and make informed decisions, but also to help develop the skills required to enable the new industries to develop and meet the technical challenges posed.

In transiting to a fully renewable energy mix a balance must be reached between the use of land and water resources for energy developments or for other uses. In 2003 77% of New Zealand's utilised land was grazed[5] primarily to produce meat and dairy products for overseas markets. Under an energy conservative future, a portion of this land would need to be turned to energy cropping. Changing land use will change the way the economy works, through the emergence of new industries associated with the changed land use, and changed balance of production. A similar situation exists for water use.

For the energy developments to be environmentally sustainable they must also be carried out in such a way as to avoid degradation of the resource. The use of fertilisers may introduce issues. The visibility of the land use changes necessary to transition to a fully renewable energy society, will lead to an improved understanding of the impact of energy consumption and this in turn will help drive primary energy conversion efficiency gains and energy conservation.

The lack of energy growth will mean that the energy infrastructure will require maintenance rather than growth. The infrastructure will need to be able to cater for the variability and distributed nature of renewable energy generation. Development of energy storage mechanisms would help alleviate some of the pressures on the infrastructure (and economy) from the variable energy sources.

Compared with the other scenarios, the energy conservation-based scenario is likely to be relatively unaffected by international changes. New Zealand is still likely to be reliant on overseas suppliers for equipment to convert or make use of its renewable energy resources, and so dependent on the availability of the appropriate technologies, or New Zealand's ability to adapt whatever technology is available to its particular use. As an example, new communication technologies developed overseas could open up new opportunities for working smarter and thereby reducing transport energy use.

Research Priorities

The priority areas of research include:

- understanding demand, user behaviour patterns and market drivers to bring about a change in energy use patterns;
- an increase in the uptake of energy efficiency, including 'Cascade Use' of energy in all sectors;
- modelling of the infrastructure for stability and longevity of the existing renewable generation and infrastructure, etc;
- development of planning tools to aid transitions in urban design towards low-energy transport and effective use of distributed generation;
- a full understanding of renewable energy resources including marine, hydro, geothermal and wind;
- improved knowledge of how to integrate a highly variable renewable component is present in the generation mix;
- mitigation of the adverse impacts of any renewable energy development including optimum balance of resource use between energy production, food production, recreation, etc. This particularly relates to land and water use;
- enhanced bio-energy production from local agriculture- and forest-sourced feedstocks, with direct use for heat/electricity or efficient conversion to biofuels and other high value products through the use of bio-refineries;
- development of energy systems and storage mechanisms to smooth the 'peaky' output from a variable renewable electricity generation mix;
- development and technology transfer of the cleanest technologies for the remaining fossil fuels.

4. CONCLUSIONS

4.1 Overview Of Research Priority Areas

At the conclusion of the workshop, participants identified the following research priority areas:

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[5] Source: www.stats.govt.nz

- research to aid changes in energy use patterns, adoption of new end-use technologies, and understanding of how energy market developments can help drive energy-efficient behaviour and encourage transport changes;
- research and modelling to aid the transformation of the energy infrastructure into a more efficient and distributed system capable of delivering the available energy efficiently and securely;
- research to identify the optimal balance of resource use and the environmental implications of this (this includes water, air shed and land use);
- research into all aspects of bio-energy from economic recovery/production of feedstocks, and bio-refinery products, including development of transport biofuels;
- research and technology demonstrations for high efficiency/low impact conversion technologies for all New Zealand energy forms, including low-carbon transport fuels;
- studies on the resource potential/characteristics of New Zealand's key energy resources of all types including marine (particularly tidal current), (low-head) hydro, wind, geothermal, oil and gas, coal and lignite and methane hydrates;
- research into the local issues of carbon capture and sequestration from the use of fossil fuels and from burning or conversion of biomass.

Table 3 provides the priority assessment for each of the energy research fields. This table is based on the discussions held at breakout sessions at the Energy Research Investment Strategy Workshop, the assessments by the Technology Experts and subsequent feedback from the energy industry. Details on the various energy research fields are provided in the Appendix.

Summary results showing the mean required importance of research for each of the research energy field with respect to the energy scenarios are provided in Table 1 of the Executive Summary.

Table 3: Research Priority Scoring for the Various Energy Research Fields

FIELDS	Themes (●) and Topics (○)	Growth	Security	Transformation	Conservation
Energy Modelling	• Publicly accessible strategic energy model: ○ demand-side; ○ supply-side; ○ modelling the impacts of policy decisions.	High	High	High	Medium
	Mean required importance of research (Experts + Energy industry)	*Medium*	*Medium*	*High*	*Medium*
Demand Side: Residential	• Retrofit and Intervention: ○ energy conservation potential assessment; ○ development of implementation strategies; ○ energy use pattern changes in response to measures and outside influences.	Medium	Medium	High	High
	• Building energy-related: ○ zero and low-energy building developments; ○ solar and heat pumps; ○ advanced materials and systems.	Low	High	Medium	High
	Mean required importance of research (Experts + Energy industry)	*Medium*	*Medium*	*High*	*Medium*
Demand Side: Industrial	• Energy efficiency uptake: ○ systems analysis, integration, optimisation; ○ impact of MEPS for industrial equipment; ○ benchmarking industrial and agricultural operations; ○ influence of changes in consumer behaviour.	Medium	High	High	High
	• Development of energy-efficient processes: ○ efficient dairy product drying; ○ efficient timber drying; ○ high efficiency industrial component development.	High	Low	High	Low
	• Fuel swapping and on-site generation: ○ multifuels for industrial sites and industrial transport; ○ fuel swapping for greenhouse heating; ○ cogen packages for rural sector and industrial sites.	Medium	High	Medium	High
	Mean required importance of research (Experts + Energy industry)	*Medium*	*Medium*	*High*	*Medium*

FIELDS	Themes (●) and Topics (○)	Growth	Security	Transformation	Conservation
Demand-Side: Technologies	• Micro-distributed Energy Systems: ○ implementation potential and barriers for microDG; ○ network integration and connectivity, standards and impacts; ○ optimisation of microDG to maximise sustainability; ○ development of distributed generation solutions.	Low	Medium	High	High
	• Network and Infrastructure Integration: ○ demand-side generation technologies demonstrations; ○ power electronics and grid connection technologies and practices; ○ fuel developments that may apply to microDG.	Low	Medium	Medium	Medium
	Mean required importance of research (Experts + Energy industry)	*Low*	*Medium*	*High*	*High*
Infrastructure	• Behavioural and Market Studies: ○ performance gains through changes in user behaviour; ○ impacts of changes in user behaviour; ○ interrelationships between infrastructure types and other physical, social, environmental and economic structures; ○ techniques to encourage and promote mode changes; ○ the effects of changing demographics and work patterns.	Low	Medium	High	High
	• Planning: ○ flexible and efficient planning methodologies; ○ optimised resource use and impacts – land, water; ○ quantifying effects of infrastructural planning; ○ transformation of infrastructure to support new energy types such as large-scale bio-energy, hydrogen etc; ○ sustainability and costs of undersupply.	High	Medium	High	Low
	• Risk management and future-proofing ○ studies on vulnerability to the effects of significant oil shortages, catastrophic failure of energy infrastructure, climate change etc, and development of contingency plans; ○ intermittent grid entry points.	High	Medium	High	Low
	Mean required importance of research (Experts + Energy industry)	*Medium*	*Medium*	*High*	*Low*

FIELDS	Themes (●) and Topics (○)	Growth	Security	Transformation	Conservation
Bio-energy	• Developing the bio-energy economy: ○ balance of land use and water use for energy, food, and fibre production, plus biodiversity and recreation; ○ impact of large-scale bio-energy development and use; ○ best practice guidelines; ○ integration of food, fibre, and bio-energy production.	High	High	High	High
	• Bio-energy resource: ○ assessment of the bio-energy resource; ○ developing bio-energy crops suited to New Zealand conditions; ○ the cost effective collection, transportation of biomass.	High	High	High	High
	• Bio-energy technology: ○ conversion to liquid biofuels; ○ upgrading biomass to aid its transportation; ○ developments for advanced anaerobic digestion; ○ lignocellulose technologies; ○ demonstration of bio-energy plant and techniques; ○ development of biomass combustion plant of all sizes.	High	High	High	High
	Mean required importance of research (Experts + Energy industry)	*High*	*High*	*High*	*High*
Solar	• Hydrogen Production: ○ from coal and lignite; ○ from biomass; ○ hydrogen clean-up; ○ electrolysis; ○ solar/hydrogen production technologies.	Medium	Medium	Medium	Low
	• Development of solar energy technologies: ○ large-scale solar technology and grid-tied PV; ○ grid connection and compatibility with the infrastructure; ○ measurement of solar resource using satellite images; ○ mid-temperature solar thermal systems; ○ alternatives to silicon-based photovoltaic technology; ○ volume PV-grade silicon feedstock.	Medium	Medium	Low	Medium
	Mean required importance of research (Experts + Energy industry)	*Medium*	*Medium*	*Medium*	*High*

FIELDS	Themes (●) and Topics (○)	Growth	Security	Transformation	Conservation
Wind	● Planning of wind energy developments: ○ environmental and societal impact studies; ○ environmental and societal integration of wind developments; ○ multiple land use.	Medium	Medium	High	High
	● Hydrogen infrastructure: ○ roadmap to a hydrogen economy; ○ codes and practices.	Medium	Medium	High	Medium
	● Wind energy technology: ○ advanced composites for wind turbine; ○ technologies for erratic or turbulent wind resource; ○ aerodynamic designs and generation technologies; ○ development of hybrid systems.	Low	Low	Medium	Low
	Mean required importance of research (Experts + Energy industry)	*Medium*	*Medium*	*High*	*Medium*
Ocean and Hydro	● Resource assessments and impacts: ○ wave and tidal current energy; ○ micro hydro sites and run-of-river sites; ○ impact assessments of marine developments.	High	High	High	High
	● Development and integration of sites: ○ environmental compliance and social acceptance; ○ site suitability and the integration of the technologies; ○ undersea mapping and device deployment.	Medium	Medium	Medium	High
	● Technologies: ○ cogen/large-scale distributed.	Low	Low	Medium	Low
	Mean required importance of research (Experts + Energy industry)	*Medium*	*Medium*	*Medium*	*Medium*

FIELDS	Themes (●) and Topics (○)	Growth	Security	Transformation	Conservation
Geothermal	● Geothermal power generation: ○ environmental impacts including subsidence; ○ field geology, connections; ○ use of power station waste geothermal fluids; ○ remediation technologies; ○ exploration and management technologies.	High	High	High	High
	● Low enthalpy resources: ○ resource evaluation; ○ capacity in low enthalpy areas.	High	High	Medium	Medium
	● Deep geothermal: ○ permeability enhancement of deep wells; ○ hot dry rocks.	High	High	Medium	Low
	Mean required importance of research (Experts + Energy industry)	*High*	*High*	*Medium*	*Medium*
Hydrogen	● Hydrogen production: ○ from coal and lignite; ○ from biomass; ○ hydrogen clean-up; ○ electrolysis; ○ solar/hydrogen production technologies.	High	Medium	High	Low
	● Hydrogen storage: ○ metal hydrides and ceramics; ○ carbon nanotubes.	Medium	Medium	High	Low
	● Utilisation technologies: ○ fuel cells; ○ novel engines.	High	Medium	High	Low
	● Hydrogen infrastructure: ○ roadmap to a hydrogen economy; ○ codes and practices.	High	Medium	High	Low
	Mean required importance of research (Experts + Energy industry)	*High*	*Medium*	*High*	*Low*

FIELDS	Themes (●) and Topics (○)	Growth	Security	Transformation	Conservation
Carbon Capture and Storage	● Carbon Capture: ○ current and potential large-scale CO_2 sources; ○ identification/assessment of appropriate technologies; ○ development of lower-cost CO_2 capture options; ○ transportation and distribution; ○ CO_2 bio-utilisation and fixation.	High	Medium	High	Low
	● Geo-sequestration: ○ quantification of New Zealand's potential capacity; ○ modelling of potential reservoirs/CO_2 interactions; ○ risk assessment of geo-sequestration options; ○ verification and monitoring; ○ legal and policy.	High	Medium	Medium	Low
	Mean required importance of research (Experts + Energy industry)	*High*	*Medium*	*High*	*Low*
Coal	● Large-scale use (electricity, gasification and chemicals): ○ coal properties; ○ advanced coal technologies; ○ lignite upgrading; ○ gas clean-up technologies; ○ syngas to product; ○ utilisation of waste.	High	High	Medium	Low
	● Industrial use of coal (dairy, meat etc): ○ new technologies; ○ cogen/large scale distributed.	High	High	Medium	Low
	● Coal production: ○ environmental impacts of mining; ○ mine site rehabilitation; ○ new mining technologies.	High	High	Medium	Low
	Mean required importance of research (Experts + Energy industry)	*High*	*High*	*Medium*	*Low*

FIELDS	Themes (●) and Topics (○)	Growth	Security	Transformation	Conservation
Petroleum and Gas	● New Zealand petroleum basins: ○ sedimentary depositional systems; ○ subsurface structure; ○ systems modelling; ○ databases, atlases and reference tools.	High	High	Medium	Low
	● Non-conventional: ○ coalbed methane; ○ gas from waste.	High	High	Low	Medium
	● New opportunities: ○ deep-water frontier oil and gas; ○ methane hydrates.	Medium	Low	Low	Low
	Mean required importance of research (Experts + Energy industry)	*High*	*Medium*	*Low*	*Low*

ENERGY RESEARCH FIELDS

This appendix explores the main energy research fields, describes the current status of research in each, both in New Zealand and internationally, and considers where this research might lead in the future. Issues specific to the New Zealand context are also outlined.

A. DEMAND-SIDE: RESIDENTIAL

Facilitator: Michael Camilleri, BRANZ Ltd

A.1 Background

The demand side of energy use is why the supply exists: no demand, no supply. By better understanding the demand side, energy consumption can be optimised to deliver maximum service for minimum energy and be better matched with supply, reducing overall costs and improving security. To manage the demand side, the demand must first be known – how much energy, of which fuel, for which end-uses, to provide which level of service.

About 70% of the energy use of residential buildings is electricity, with high peak winter evening loads, which puts a disproportionately high demand on the electricity generation and distribution network. Residential electricity use continues to increase at 1-2% per year, driven mainly by an increasing population, decreasing numbers of people per house, and changing consumption patterns.

The Household Energy End-Use Project (HEEP) is a major, long-term research project that has monitored energy, temperature and other data in New Zealand households. It is the largest study of this kind in the world, and no other contemporary study comes even close in scale or coverage. HEEP has and will provide an excellent baseline picture of energy demand in residential houses.

A.2 International Research Activities

Zero- and Low-Energy Houses

Internationally there are many examples of houses that use zero or very low energy, even in extreme climates. These houses use passive heating and cooling, super-insulation and thermal mass storage to reduce or eliminate dedicated space heating and cooling energy. Efficient appliances are used, sometimes powered by alternative energy supplies.

Research issues include:

- achieving zero or low energy in a particular climate;
- building such a house at reasonable cost;
- acceptability of the designs to the housing industry;
- making sure they still work when real people live in them.

Rating Schemes for Houses

Energy and environmental rating schemes have been developed for most Western countries and many Asian countries also. These schemes rate the energy and environmental performance of a house against a set of criteria. In some places these schemes are compulsory for new houses (or even on the resale of existing houses) to inform the buyers of the performance of the house, or as a regulatory mechanism for implementing a minimum performance standard.

Energy Retrofit Studies and Programmes

Many retrofit studies and programmes attempt to quantify the savings and improvements made, recognising that simple engineering calculations of potential savings are often not realised in practice. A large body of practical knowledge is being built up of the issues and problems that are encountered in real life that can be the difference between success and failure of a program.

Advanced Building Materials and Services

Advanced building materials and services include: vacuum-insulated panels; advanced solar panels; advanced glazing; heat pumps (both air and ground source); solar and heat pump hot water; active solar heating systems; distributed network control of appliances; smart metering.

Residential Sector Energy Models

Various residential sector energy models are in use or in development internationally. They are used for a variety of purposes including research, consulting and policy development. Getting good-quality data for these models is often difficult.

A.3 New Zealand Research

New Zealand-Specific Issues

Specific New Zealand issues that need to be researched include:

- energy conservation resource estimation. Update Wright and Baines' 1986 report (Supply Curves of Conserved Energy: The potential for conservation in New Zealand's houses);
- retrofit and intervention studies in typical New Zealand houses;
- practical zero- and low-energy houses for New Zealand climate and people.

IP Opportunities
IP opportunities include:

- zero and low-energy house designs and supporting technologies;
- practical knowledge of retrofit and intervention effects for designing programs.

Watching Brief
Areas of 'watching brief' status include:

- zero and low-energy housing programmes internationally;
- solar and heat pump technology;
- advanced building materials and systems;
- retrofit experiences.

Other Activities
BRANZ Ltd and Building Research already maintain connections with and a 'watching brief' on many international developments relevant to buildings through participation in New Zealand and international Standards bodies such as the IEA and APEC, and professional and business contacts.

A.4 Energy Scenarios

Primary Industry-Led Growth
The large growth in energy demand comes at the cost of increases in energy generation and transmission costs and higher electricity costs. Energy efficiency becomes more cost-effective for the house occupant, and also a better investment opportunity for deferring investment in generation and transmission capacity. However building more generation and transmission capacity is likely to be the main means of meeting demand.

Energy Security
Reductions in electricity demand at peak times and times of hydro shortage are paramount. Power companies move to time of use metering to send price signals to residential customers. There will be a big move from electric space heating (which is a major peak demand) to more efficient appliances (e.g. heat pumps), or other fuel sources (e.g. wood, gas, LPG) as peak prices climb.

Energy efficiency is also very important, with higher insulation standards for houses and appliances, and a push to retrofit the existing housing stock.

Economic Transformation
This is similar to Energy Conservation, with increased regulation of houses for energy efficiency, both in new and existing houses. Low energy, highly efficient houses and appliances become the norm. There will be a big increase in solar and heat pump for space heating and water heating. Emphasis will be on improved comfort and service in houses with less energy use.

Energy Conservation
There will be increased regulation of houses for energy efficiency, both in new and existing houses, and a major push for alternative energy sources (e.g. solar hot water), GHG-neutral sources (e.g. wood) and higher efficiency (e.g. heat pump hot water and space heating).

Energy efficiency and conservation are important under all scenarios.

B. DEMAND-SIDE: INDUSTRIAL

Facilitators: Gerry Carrington, Department of Physics, University of Otago, and Hamish Trolove, CRL Energy

B.1 Background

Industry is the most significant generator of wealth within New Zealand but also one of the largest energy consumers. For the purposes of this document, we have included all primary production under this discussion of industrial energy research. Industry uses a diverse range of energy sources, for an equally diverse range of end-uses. This diversity makes it difficult to identify across-the-board energy research, but it also offers opportunities for research into energy source changes and niche research. Despite the range of industries, there are a number of elements that are common to most, and these represent opportunities for research.

Industrial energy use in New Zealand is dominated by a handful of energy-intensive industries that tend to have their own on-going research programmes looking at achieving efficiency improvements from their existing technologies. These companies are commonly owned by international consortiums and so there is some scope for their researchers to draw on overseas research by their peers working under the same consortium. All research work into fundamental changes to the technologies is at present done overseas, as New Zealand has neither the research capability nor the number of potential end-users to support such a research programme. An exception exists in Fonterra, where a research programme on energy efficiency and systems analysis is presently active in conjunction Waikato University.

Figure 4: Industrial Energy End-Use (1998) Excluding Freight Transport[6]

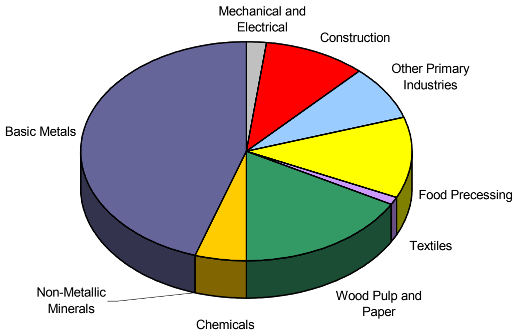
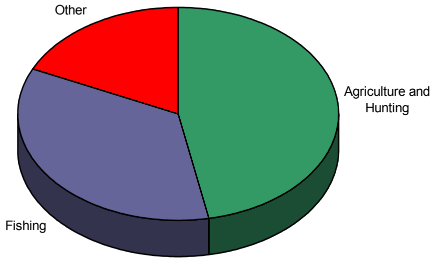


Figure 5: Primary Production Energy End-Use (1999)[7]



Due to the specific needs of a particular industry, some research is carried out in-house and is generally very tightly targeted on technology improvements. As this research is often commercially sensitive, it is very difficult to get a picture of how much in-house research is done.

Much of the focus for industry is on gaining efficiency. For the most part, the technology is available commercially but the barrier is implementation. The focus at the policy level is on encouraging uptake of the available energy efficiency measures.

Supporting gains in energy efficiency are research programmes that aid waste minimisation and recycling initiatives. Although these are energy efficiency research programmes in an indirect sense, they can play a large part in reducing a company's energy use and requirements for raw materials, both of which will improve the company's profitability.

B.2 International Research Activities

Energy research for industry tends not to be carried out at the industry level but rather on the component level. Development of new pumps, dryers, heat exchangers and the like is an on-going process driven by the component manufacturers. In the case of high energy intensity plant such as for cement and aluminium production, new, more efficient plant is always being developed by the companies who supply the equipment. The research required to support this is concerned with how to ensure the high-efficiency solutions are installed and operated efficiently. The key is to undertake research into systems analysis, systems integration and systems optimisation, to ensure that the new component technologies developed overseas can be shown to enhance energy efficiency, as well as to make process improvements, as appropriate. This requires engineering researchers to work closely with factory owners/operators, and sometimes with industry consultants, to undertake the appropriate analysis, and if necessary, modelling, to ensure that there are real gains to be realised. The gains may partly lie outside the factory and result in less electricity generation/fuel use and therefore may have a significant public good element.

Benchmarking

Internationally there have been a large number of programmes to develop energy benchmarking for industries. This is so that the performance of industries can be compared one with another and against changes in their own performance over time. By having good benchmarking data, an industry can measure and monitor their performance which can in turn highlight areas where improvements can be made, with a resulting increase in profitability.

Pinch Technology

Pinch technology or process integration is the systematic study of the heat flows in a process to identify opportunities for process optimisation, using the waste heat from one part of the process to provide heat and materials to a different part of the process. The research around this subject tends not to be based on technologies, but rather on systems, and modelling.

As the major New Zealand industries engaged in processing raw materials (dairy, pulp and paper) generally employ batch processing - as opposed to the continuous processing for which current pinch technology was developed and is ideally suited - there is a need for New Zealand researchers to adapt pinch technology to batch processing. The co-location of industries would seem to represent a major opportunity for energy efficiency gains to be made in New Zealand, through cross-site heat integration, and the extension of pinch technology to batch processing is an important means to show the benefits, or otherwise, of co-location, particularly where processing loads vary and hence the heat production available for integration across sites also varies.

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[6] *The Dynamics of Energy Efficiency Trends in New Zealand: A Compendium of Energy End Use Analysis and Statistics* Dr Harbans S. Aulakh, EECA, 2000 Edition

[7] *The Dynamics of Energy Efficiency Trends in New Zealand: A Compendium of Energy End Use Analysis and Statistics* Dr Harbans S. Aulakh, EECA, 2000 Edition

B.3 New Zealand Research

Within New Zealand there is very little research done into the design of efficient components due to the small size of our market, and the fact that most of the components used in industrial processes are imported. On the large-scale industrial sites, there are often in-house research projects looking at improving the efficiency of the key equipment, but just as often the potential for system-based studies of supporting services are overlooked. The same is true of the smaller industries. At present, there are several industrial research projects on drying which are targeted at the timber industry. A programme of work is also active which looks at reducing electricity consumption in the industrial sector through analysing compressed air systems for the milk processing and the pulp and paper industries. This research is providing technical data that will help these industries better match supply and demand for the air used in their processes.

If researchers were to concentrate on energy/process systems analysis, integration and optimisation, large gains in energy efficiency in existing factories could potentially be made. With the understanding such research would yield, innovative redesign of existing systems could achieve significant energy savings, and provide a basis from which to evaluate additional gains that may or may not be achieved by the proper integration of new components or technologies.

In the primary production industry, no such energy research programmes are active. As most energy use in the sector is from vehicle use (ships, tractors, logging trucks), only new technologies from overseas and smarter use of existing technologies will have an impact on energy efficiency. At present, there exists some potential for research programmes to design smart solutions for efficiently providing process heat in dairy sheds and reducing energy use in greenhouses.

New Zealand-Specific Issues

New Zealand industry faces a number of issues when it comes to improving energy efficiency, but these are little different from those faced by industry the world over.

One of the most important issues facing industry in New Zealand is attracting and retaining technical skills in an environment where technical understanding is declining. Although this is not energy research, it impacts both on energy research and the ability of the industry to implement energy use improvements. Giving local processing industries improved access to new, high-level science and engineering methods and skills will help enable energy efficiency gains. To date, local processing industries have had limited research budgets, and have tended instead to have preferred supplier arrangements with technology companies based overseas. New Zealand-based consultancies are generally small and necessarily serve the immediate needs of industries, and do not by-and-large have the funding to develop and maintain high-level science and engineering skills and capabilities. Although some local researchers - particularly young researchers - possess these skills, few are employed in New Zealand industry. If New Zealand means to maintain the export competitiveness of some of its key industries, however, it is vital that these industries link with researchers who possess the high-level science and numerical skill-sets necessary to conduct systems analysis, integration and energy optimisation. The country stands to gain by forging links between high-level researchers and industry, and by providing encouragement or incentives for researchers to go into factories".

Currently, little attention is devoted to energy efficiency in New Zealand industry outside the very large users. An important area of research is the development of policy programmes and associated monitoring to aid the uptake of energy efficiency measures.

New Zealand is behind the rest of the world in its application of MEPS (minimum energy performance standards). The catch-up process is underway, but still has a way to go, particularly with regard to MEPS for industrial equipment. There is some research potential around the development of MEPS, their impact and the appropriate products to target.

IP Opportunities

Some opportunities exist within New Zealand to develop niche research in the following areas and so generate potentially valuable intellectual property. These opportunities include:

- development of efficient timber drying technology;
- development of energy efficiency in dairy processing systems;
- tools to benchmark on-farm energy use, and fishing industry energy use;
- developing packages for farm energy generation through biogas digesters, and remote area power systems (with the potential for application to third world countries);
- development of energy-efficient on-farm dairy systems.

Capability Building

Due to fluctuations in the availability of traditional fuels and the costs of upgrading infrastructure, there is a growing need for New Zealand to build capability in the following areas:

- rural remote area power generation;

- fuel swapping for industrial plant and industry transport fleets (i.e. forestry trucks, mining fleets, and dairy tankers);
- retrofitting greenhouses to be more energy-efficient and to run on alternative sources of heat;
- benchmarking industries of all types.

Watching Brief
As it relies on overseas suppliers for most of its industrial components, New Zealand will need to keep an eye on overseas developments around technologies for high energy intensity industries to see when they become available and ensure that may be successfully implemented. Systems analysis, integration, and optimisation may be necessary to ensure the technology is implemented to the best effect.

Other Activities
Internationally, benchmarking studies are being developed for most industries and are used by policy makers and the industries themselves. New Zealand needs to increase the amount of benchmarking and energy use comparisons it performs to promote best practice in energy use and maximise the returns to industry on their energy spend. However, benchmarking studies will need to be carried out in conjunction with good science and research, an up-to-date knowledge of each industry's best practice, and a systems analysis approach to ensure the best outcomes are identified and sufficient technical backup is present for implementation.

It will be necessary to increase the number of pinch technology-based studies carried out on industry, and to adapt the technique to suit the batch production which is very common in New Zealand industry.

It will also be necessary to monitor and adapt overseas MEPS to New Zealand conditions and to carry out research into the effects of implementing MEPS on New Zealand's economy.

B.4 Energy Scenarios

No matter which way the future develops, industry of some sort will remain. The nature of the industry which remains will vary according to the scenario, but the underlying process services and methods for improving the energy use of industry will remain the same.

Primary Industry-Led Growth
Under the high growth future, where primary industries tend to dominate, the emphasis will fall on keeping energy costs down, either through maximising energy efficiency or minimising the risks of downtime from energy supply failure. New energy-intensive industries, including transport fuel production, are likely to be a key component of the scenario.

Priorities for demand-side industrial energy research under the primary industry-led growth scenario are:

- research to support new energy-intensive industries, including transport fuels from coal and biomass;
- research around adaptation of the existing industries to use multiple fuel types in order to spread the risks arising from the supply failure of any one fuel type;
- research which may yield gains in transport efficiency by developing dispatching technologies that suit New Zealand's primary production types;
- pinch technology, which will be relevant under the high growth scenario, as it will achieve process efficiency gains;
- systems analysis, integration and optimisation to help achieve efficiency gains through the identification of process improvements, and to evaluate the energy efficiency merits of new components/technologies.

Energy Security
In a future where energy security and self-sufficiency are paramount, it is possible that heavy industries manufacturing products that are almost all exported will be scaled back or disappears. Those industries remaining will need to implement energy efficiency measures as a result of a much more regulated environment.

Priorities for demand-side industrial energy research under the energy security scenario include:

- research to identify key drivers for behavioural change within industry and develop programmes to ensure the uptake of energy conservation solutions and fuel switching;
- research to support the production of transport fuels from New Zealand resources;
- research around the adaptation of existing industries to use multiple indigenous fuel types in order to spread the risks arising from supply failure of any one fuel;
- MEPS and regulations will need to be developed and its impacts assessed;
- pinch technology, which will be relevant under the energy security scenario as it will achieve process energy conservation;
- development of remote area power systems (RAPS) will help provide back up for isolated rural communities. This research includes on-farm power generation;
- development benchmarking tools and studies, which may be relevant to this scenario as it will provide a method of measuring the effect of regulations and voluntary energy conservation measures;
- systems analysis, integration and optimisation to help achieve efficiency gains through the identification of process improvements, and to evaluate the energy efficiency merits of new components/technologies.

Economic Transformation
Under a future where the economy is transformed to weaken the link between energy use and GDP, the nature

of the industries present in New Zealand will change from high energy intensity to lower energy intensity, higher added value.

The essence of the transformed economy is working smarter and so the emphasis for energy research will be in the following areas:

- research to identify key drivers for behavioural change within industry and develop programmes to aid the uptake of energy-efficient solutions;
- research to aid utilisation and integration of renewable energy generation (particularly solar) into industrial and primary production processes;
- continuing development of pinch technology for energy-efficient production at all levels;
- research to support MEPS programmes, and their extension to the industrial and primary production sectors;
- development of benchmarking tools and databases, which will provide valuable information to industry and government on opportunities and effects of energy efficiency measures;
- pinch technology, which will be important for smart use of energy within processes, thereby leading to greater efficiency gains;
- systems analysis, integration and optimisation to help achieve efficiency gains through the identification of process improvements, and to evaluate the energy efficiency merits of new components/technologies.

Energy Conservation
Under this scenario, the emphasis for industry will be on smart use of energy and resources as well as the integration of renewable energy opportunities. To support these, a comprehensive education programme will be necessary. Important research areas for industry and primary production sectors under this scenario will be as follows:

- research to identify key drivers for behavioural change within the industrial and primary production sectors and develop programmes for both sectors to aid the uptake of energy-efficient solutions, energy conservation and fuel switching;
- research to develop pinch technology and cascade technologies to a high level and ensure their effective use in the maximum number of sites within the industrial and primary production sectors;
- development of benchmarking tools and databases, which will provide valuable information to industry and government on opportunities and effects of energy efficiency measures;
- research to support MEPS programmes and their extension to the industrial and primary production sectors;
- development of remote area power systems (RAPS) will help provide backup for isolated rural communities. This research would include on-farm power generation;
- research to aid utilisation and integration of renewable energy generation (particularly solar) into industrial and primary production processes;
- systems analysis, integration and optimisation to help achieve efficiency gains through the identification of process improvements, and to evaluate the energy efficiency merits of new components/technologies.

C. DEMAND-SIDE: GENERATION TECHNOLOGIES

Facilitator: Alister Gardiner, Industrial Research Limited

C.1 Background

This field covers distributed (on-grid) and stand-alone (off-grid) micro scale generation – which is normally taken to include technologies applied at less than a nominal 100kW capacity. These technologies are often small versions of industrial scale plant such as diesel gen-sets and gas turbines, or renewable energy generation systems based on solar PV, small wind turbines and hydro generation. For the purposes of this report, the field also covers other small electrical conversion application such as water electrolysis (for hydrogen production) and combined heat and power systems (e.g. domestic boilers which also produce electricity). Generally speaking, these technologies are differentiated by the scale at which they are connected to the electricity distribution network and the ensuing market arrangements, rather than the uniqueness of the technologies themselves. In principle, micro-generation could be installed at any power rating up to the load capacity of the connection. In New Zealand, general connections are normally supplied at 60A or 100A, single phase to 3-phase, i.e. 14kW to 66kW of load. Micro-generation is usually connected 'behind the meter' of normal residential and small business general-customer sites. Because of this, and the small individual capacity of each generator, standardised regulations are necessary to allow realistic access to the network by owners of these technologies. Regulations often limit the connection capacity to below the technical potential and also define the market access framework, which may not necessarily be to the benefit of the customer-generator.

C.2 Application Areas

Remote Area Power Systems (RAPS) Or Off-Grid Generation (Including Standby Generators)
RAPS have been the traditional focus of small energy systems research, to reduce costs and improve the convenience of remote area power supplies. More recently, research in this area has focused on the introduction of hybrid systems, such as the integration of renewable energy resources such as wind and solar PV with diesel gen-sets and batteries. Because of the need for storage to cater for generation-load mismatch, and the

lack of network load diversity (i.e., the entire load has to be served by the local generation all of the time) RAPS systems are considerably more expensive per kW than network systems serving the same load base size. Accordingly, with growing constraints on the development of large schemes, and increasing fuel and electricity prices, a bright future is seen for network connection of small generators, both fossil-fuels-based and renewable. In particular, fuel cells and photovoltaic cells are both seen as key technologies for grid-connected applications. These markets are currently growing at 30-40% per annum, spurred in a large part by early market incentives in a number of countries.

Distributed Generation (DG) Or On-Grid Generation

DG is the connection of generation systems embedded within the network. These technologies are being encouraged in many countries because they improve security of supply by creating diversity of fuel types, locations and technologies and where appropriately sited, can reduce the need for transmission and distribution upgrades. Furthermore, some new distributed generation technologies utilise local renewable energy resources and others increase the efficiency of use of fossil resources over conventional generation technology. This second aspect is a key reason for global research efforts to develop distributed generation fuel cell systems for residential and small commercial customer use. Because these technologies are potentially disruptive to the existing electricity supply markets (i.e. competitive) but on the other hand environmentally and economically desirable, governments see it as important that there are no unnecessary barriers to their development and uptake. Many countries are providing supportive environments to encourage uptake of micro-generation, and this is fostering massive overseas research and development efforts.

C.3 Trends And Areas Of Research

The two main markets for demand-side generation technologies are on-grid and off-grid.

Many aspects of these generation systems are common for the two markets. However, to be competitive, on-grid fuel-based generators need to deliver combined heat and power (CHP). For inverter-based systems (e.g. fuel cells and PV), the connection requirements for on-grid and off-grid are different. Control and management requirements are also different, and more specifically, off-grid systems are required to deliver the full instantaneous power demand of the load at all times. This is not a necessary requirement of on-grid systems because the network can provide a temporary battery function, and so on-grid technologies can be simpler. Off-grid energy systems usually consist of a mix of technologies such as a diesel gen-set, wind generator, and battery bank.

New sustainable on-grid technologies are expected to play a major part in the transformation of the electricity infrastructure in developed countries. The EU has allocated 890 million euros funding for RTD in this and similar fields under FP6: Sustainable Energy Systems. Specific micro-CHP generator development has attracted 12 million euros of funding.

The main drivers for research effort to introduce these technologies are:

- environmental imperatives - the need to reduce climate-changing GHG emissions and air pollution, in the case of DG, through renewable generation and improved efficiency;
- constrained traditional energy resources – to maintain energy supply security where there is inadequate delivery infrastructure, competition for resources;
- affordable energy - society well-being, international competitiveness.

Micro-scale distributed energy can contribute to addressing these issues by achieving a substantial reduction in resource use through increased supply efficiency and the uptake of renewables.

There are a large number of potential technologies and variants that could be applied to micro-scale power generation, but these relate to only two main classes of energy resources which are locally available and applicable to the conversion technologies in the research area, namely:

- direct renewable sources – solar, wind, hydro, marine;
- fuels – fossil and renewable (NG, LPG, diesel, petrol, methanol, ethanol biomass).

Some of the technologies which can be applied at the micro-scale include:

1. Combined Heat and Power (CHP):

- fuel cell systems;
- fuel-based heat engines.

2. Renewable Generation Technologies:

- hydro, wind, PV, marine and solar thermal-based, biomass, geothermal and ground-source heat pumps.

3. Storage devices and other conversion technologies:

- batteries;
- supercapacitors;
- electrolysers for hydrogen production/storage.

4. Inverters and interconnection:

- on-grid (grid interactive);
- off-grid (stand alone).

C.4 Subfields Of The Research Area

Because of the wide range of technologies in use, and widespread application markets, the key technologies including main research trends are briefly described below.

Fuel Cells
Prior to the development of a hydrogen infrastructure (by no means certain in reality or timescale), these systems need to operate from available fuels such as natural gas, LPG, diesel and possibly ethanol, and so they require an integrated fuel processor. There are a number of candidate fuel cell technologies for micro-scale applications. Most operate with electrical efficiencies between 30-50% and at temperatures from 50 – 800°C. Development of systems with a high overall CHP efficiency is expected to make these micro-generator appliances highly competitive in many off-grid and on-grid markets. Research is required to improve the fuel processors and the fuel cell operating life, and to achieve large cost reductions, before commercial uptake can occur. There is a need to understand and proactively to manage the impact of large-scale uptake on the network, particularly in regard to load profiles, power quality and market issues.

Market trends – Present installations number several thousand and are mostly demonstration level. Both the EU and the USA DoE predict substantial stationary fuel cell installations by 2010. For 1-10kW stationary fuel cells, ABIResearch predict a global capacity of 4,516 MW by 2013, just 8 years away. The EU is predicting up to 60GW of FC generation in the European Community alone by 2020. Market kick-off is expected around 2006.

Heat Engines
There are two main classes of heat engines suitable for demand-side generation: modified automotive reciprocating engines, and micro-turbines. Efficiency and emission improvements are still being made in automotive diesel engines and this will filter through to stationary applications. Micro-turbines are derived from aero-engines and truck turbochargers, and have long operating life but relatively poor efficiency. Fuels include traditional fossil fuels, and increasingly renewable fuels derived from biomass (e.g. biogas and syngas), are being used for microscale and larger DG.

Several companies are also developing integrated Stirling engine generators (e.g. Whispertech in Christchurch). Because of their low efficiency, small on-grid heat engines must operate on low cost fuels such as natural gas, and also be matched to a relatively large local heat load: e.g., domestic boiler duty. Natural gas engine generators are of increasing interest for CHP, and the large manufacturers are undertaking development to improve their efficiency and emissions performance. The viability of these systems is based primarily on the gas-electricity price differential and this is not particularly attractive in New Zealand. Emissions and noise/vibration are usually also problematic, so in general they are only deployed at larger ratings (>100kW). A fundamental improvement in ICE technology is required to achieve the efficiency necessary for widespread grid-competitive applications. Some work is being undertaken overseas on advanced ICEs: for example, the development of hydrogen-fuelled engines using ceramics for high temperature and high efficiency (potentially 60%).

Network operator Orion Energy has demonstrated the value of customer-managed engine generators for supporting the distribution system during peak demand periods. The viability of using standby diesel gen-sets in this mode is based on the capacity value and not the small amounts of expensive energy produced.

Market trends – market growth is expected to be steady for off-grid applications, with research efforts being made to improve the performance and economics of renewable fuel systems. Due to the above-mentioned disadvantages, only modest network-based uptake at the micro-scale level is expected in applications where the heat output can be matched to the demand and noise/vibration/emissions are manageable.

Small Renewable Generation Technologies, Including Hydro, Wind, PV, Marine, Solar Heat Engines
While these technologies are also being developed for application at a larger scale, it is important to recognise the growing opportunity being created through regulatory change for on-grid small-scale systems. Micro-scale renewable technologies can be network connected, and will become increasingly competitive as production volumes rise and grid-supplied electricity costs continue to trend upwards.

Market trends - Rooftop PV is expected to continue to show impressive market growth due to support mechanisms in many countries (global production increase has been >30%/year for the last 10 years and is expected to continue at this rate). Research continues in efficiency improvements, cheaper materials technologies and reduced manufacturing costs. An upsurge in small network-connected wind turbines and hydro generators in rural areas is expected and development of lower cost interconnection technologies is required. However, small wind systems are not likely to have a significant impact on the network. The other technologies identified (marine generation and solar heat engines) are still embryonic and are not likely to have an impact before 2015. New Zealand wave energy resources are substantial and this offers a local research opportunity. Solar thermal generation requires strong consistent sunlight and so is not particularly relevant to New Zealand. For the near-term network technologies such as PV, there is a need to understand the implications and impacts of large-scale uptake on the network.

Storage Devices and Other Conversion Technologies

After over a century of use, lead acid batteries still offer the best cost performance for stationary battery storage. However, electricity storage is not yet cost-effective in on-grid applications. Advanced battery research continues for vehicle applications and significant progress has been made with lithium-ion technologies. Spin-off applications are possible in stationary generation/storage if vehicle uptake reduces the costs dramatically.

Super-capacitors offer best performance for short term storage in the range of 1 second to 1 minute, but again await large scale hybrid vehicle market uptake to drive costs down. These devices may find application in buffering fuel cells, but will not be in demand until fuel cell technology is proven.

Hydrogen is being investigated for longer-term energy storage, because of the ability to decouple the conversion technology (electrolyser-fuel cell) from the energy store (hydrogen). However, the associated hydrogen technologies are still very costly and the development of lower-cost systems involving pressurised electrolysers and fuel cells is necessary to eliminate or at least reduce the hydrogen compression cost. Hydrogen applications are envisaged for small-scale and community RAPS systems as well as grid-based storage of renewable energy and hydrogen production for fuel cell vehicles in the longer term (2015 on).

Market trends – In the short to medium term (before 2015), these storage technologies will not have much network impact. In the longer term, as the electricity infrastructure becomes the dominant means of energy T&D, it is possible that some of these technologies will play a very significant role.

Inverters and Interconnection

High performance inverters are essential for interconnecting DC sources to distribution networks. This includes fuel cells, solar PV, small wind generators, micro-hydro systems and possibly future wave energy generators. The major new inverter markets are for on-grid PV and fuel cells. These have different individual inverter input requirements. Improvements in inverter technologies are continuing. Some systems now offer 95% or better peak efficiency. Improved broad-range efficiency and cost reductions are still possible, through more sophisticated circuit design and volume production. Power electronics is a market area that New Zealand has done very well in and could benefit from applied research in niche inverters and interconnection technologies. There is a need to understand the implications and impacts of large-scale uptake of inverters connected to the network infrastructure and the benefits possible from development of smart electricity networks using these technologies.

Market trends - Frost and Sullivan predict high market growth for these technologies. The total inverter market for renewable energy systems will grow to $US4,134M by 2011, and a compound annual growth rate of 40%.

Two Key MicroDG Technologies for the Short to Medium Term

Of all these options, only two micro-generation technologies have the potential for widespread, very large volume uptake on the demand side (i.e. residential and small commercial) – these are solar photovoltaics and fuel cells. International research interest in both of these technologies is very strong.

C.5 International Research Activities

Different markets around the world have differing rules for the connection of micro-generation systems, depending on their policy towards encouraging uptake. Most OECD countries have introduced incentives for the development of micro-scale distributed generation, although the mechanisms used are varied.

The EU research vision for micro-generation is to achieve transformation of sections of the supply infrastructure to become self sufficient in generation. In residential networks, an average of less than $500W_e$/connection is required to make a network area self-supporting. This energy supply level is easily within the capacity of rooftop solar and residential fuel cells. The EU has allocated 890 million euros for RTD (Research and Technology Development) funding in this and similar fields under FP6: Sustainable Energy Systems. Specific Micro-CHP generator development has attracted 12 million euros of RTD funding.

The main research effort internationally is being applied towards:

- solar generation technologies – while solar PV generation has been commercial for niche markets for 30 years or more, continual improvements are being sought through intensive research in both PV materials efficiencies and in reduction of the manufacturing cost of commercial systems. A technology learning curve (reduction in cost per doubling of cumulative production) of around 0.8 has been maintained, which should make PV competitive in many grid-connected markets by 2010. Because of the highly sophisticated research facilities and large teams required it is unlikely that New Zealand can contribute significantly to world IP achievements in this area;
- micro-CHP technologies – the second large area of research internationally is the development and commercialisation of residential and small commercial business level CHP generator technologies which can dramatically reduce the hydrocarbon fuel input required from either renewable or fossil sources. Renewable sources are costly and difficult to transport and concentrate, so

efficient distributed use is beneficial. Fossil fuels emit GHGs, so any efficiency improvements lead to reduced emissions as well as conservation of a dwindling resource. The majority of funding is being applied to fuel cell improvements and integrated hydrocarbon reformers to achieve reliable operation from readily available fuels. Many fuel sources are being considered, including natural gas, LPG, methanol/ethanol, biogas, syngas etc. The aim is to achieve high efficiency of energy delivery.

Micro-CHP technology is less developed than PV, but potentially the more significant of the two. Distribution infrastructure transformation is unlikely to occur without successful development of fuel cell generators for CHP, because this is the only technology which can offer the reliability of supply characteristics necessary for wide spread uptake. These two conversion technologies both use electronic inverters for interfacing the network and this is also driving research to improve inverter efficiency and reduce costs. Inverter efficiencies now generally exceed 90% over a wide power operating range.

C.6 New Zealand Research

The main national energy strategy drivers for these technologies are simple – on the one hand, increased capture and sustainable use of local renewable resources, and on the other, significantly improved supply energy efficiency. These potential improvements apply equally to New Zealand as elsewhere. In New Zealand, 139PJ of consumer energy is used per year, while a massive 172PJ additional energy is lost in transformation. Most of this is from the heat wasted in central generation and from top-down transmission and distribution losses. The uptake of distributed generation CHP alternatives can deliver up to 100% energy efficiency improvements for every kWh of electricity produced.

New Zealand-Specific Issues

At present there is a lack of uniform standards and regulations to govern the introduction of small distributed generation in New Zealand. Technology design and system control depend on the specific regulations for network connection and also on the market rules adopted. These are important areas of research effort, targeted specifically to New Zealand conditions and requirements.

To take advantage of the benefits of these emerging supply options, applications research is needed to address potential barriers, identify and promote the national (public good) benefits, evaluate the technical and market impacts and adapt, develop, demonstrate and initiate manufacture of technologies within New Zealand.

Specific technologies for capturing local intermittent renewable energy such as wind generators, micro-hydro generators and solar PVs are in the main well-developed and proven. These do not need further research, apart from continual design improvement and exploration of the issues associated with integration and interaction with the existing energy delivery infrastructure. This interaction can be covered via research as highlighted below. The major new specific technology development opportunity for demand-side generation research lies in fuel-based micro-generation. Because of its potential to provide firm capacity which can support intermittent generation from renewables, introduction of this technology can enable the eventual widespread uptake of small renewable generation.

RTD is needed to understand and develop micro DG infrastructure transformation potential — assessment of the impact that combinations of these technologies could have on national source-to-service energy efficiency, how they could integrate with other demand-side measures, policy instruments, public attitude, market mechanisms, barriers, and possible scenarios for technology penetration. Research effort in this area to identify and develop niche or New Zealand-specific solutions could provide substantial returns in supply energy efficiency, improved network efficiency and technology IP and commercialisation.

IP Opportunities

While we share the opportunities and needs for new energy solutions with other countries, New Zealand has specific requirements and market conditions, particularly at the small-scale user interface level. By developing niche solutions that suit the New Zealand energy market, we have the capability to transfer these to other markets where many times greater value can be created through IP and know-how. These could particularly relate to distributed energy for rural communities that integrate intermittent renewable options with high-efficiency, fuel-based generation to achieve grid-level reliability. For example, this could lead to world-leading expertise in rural micro-grid solutions.

The global market for new micro-generation technologies provides excellent value-creation opportunities for New Zealand SME industry. This could involve IP creation from niche area research and development into materials, components, systems and products for this massive growth market (30-40% growth per annum is expected for the next decade at least). Appropriate technology areas for New Zealand device RTD derive from identifying the market application opportunities via the bullet point above. A portion of this work would be expected to focus on fuel cell systems, but by no means exclusively — there are many opportunities for improving the efficiency of bio-fuelled IC engine systems through fuel processing, improved co-generation and tri-generation, etc.

Capability Building

It is essential to build an understanding of the various micro-generation alternatives so that we can be potential leaders in niche applications of these devices and at least fast followers for broader market uptake. Specific capability building is required in power electronics and grid connection technology relevant to New Zealand network and market interactions. Since solar photovoltaics and fuel cells are the most promising micro-technologies for widespread New Zealand adoption, there is a need for New Zealand to keep well abreast of research progress and best practice.

Watching Brief

We should keep a watching brief on all forms of fuel developments such as methanol, ethanol and hydrogen. International moves in hydrogen production for a transport infrastructure will create a new pollution-free and potentially more cost-effective fuel for micro-generation systems. Biofuel production techniques and utilisation in distributed generation systems developed overseas could also be advantageously adopted here.

Other Activities

Large-scale uptake of micro-scale generation technologies that represent a move towards a more sustainable energy system requires significant behavioural change. We need to understand how these systems can and should be integrated with the supply side to the best advantage to New Zealand. Owners of generation appliances will take more responsibility for their electricity supply, just as they do for heating and other home services. Environmental responsibility will play a greater part in energy choices. Research into how the best sustainable energy outcomes can be achieved is necessary. Demonstration, deployment and diffusion are essential to this process.

C.7 Energy Scenarios

Since growth in demand-side generation technologies involves infrastructure change, it will not occur without government-led government-industry partnership. This requires a great deal of strategic thinking on the part of all stakeholders. It will take a significant shock (economic, social or environmental) for the benefits of (or need for) a transition in the energy distribution infrastructure to be implemented. This shock could be the serious and immediate consequences of global warming, peak oil or a major international conflict. All of these situations are increasingly likely and if any one occurs it may rapidly push New Zealand away from the Primary Industry-Led Growth scenario into one of the other three. An overall, possible effect of the various scenarios on the need and potential uptake of research in the main technology subfields is given below.

Primary Industry-Led Growth

Because the emphasis in this scenario will be on large-scale, supply-side solutions to continued growth in the demand for fuel, the market environment will not be supportive of infrastructure transformation alternatives that cannot provide an immediate large impact. The government will not be interested in leading change in a BAU growth environment unless forced to act because of abrupt external change. Research into network infrastructure interfacing and application issues is still needed because this scenario is likely to transition into one of the other three. More importantly, even if successful innovation in new energy technologies is unexploited in New Zealand, this could have high value on the international market, so should be treated as contestable research alongside other industry development initiatives.

Table 4: Possible Effects for Primary Industry-Led Growth Scenario

Subfield	Effect
Fuel cells	Delayed uptake, due to BAU attitudes of supply industry and policies and disinterest by government in supply chain efficiency.
Heat engines	Because of demand growth, modest opportunity for small industrial CHP applications.
Small direct generation renewables	Not likely to be implemented, due to BAU attitudes of supply industry and no specific government policy to promote renewables.
Storage and other conversion technologies	Not likely to be implemented, due to large-scale energy supply from coal, hydro and possibly LPG/NG.
Inverters and interconnection	Limited use, constrained primarily to off-grid applications and environmentally conscious sections of the public. Limited regulatory access, because the energy market is dominated by the supply industry. Micro-scale energy costs in New Zealand remain high.
Manufacture of micro-scale energy technologies	Little support for New Zealand manufacture from local energy supply industry - opportunities will be export-led.

Energy Security

In the past this environment has fostered considerable innovation and energy self-determination (geothermal, SWER, hydropower). Therefore, the need for improved energy security will encourage local innovation in micro-generation and a strong research component is needed to support this uptake.

Table 5: Possible Effects for Energy Security Scenario

Subfield	Effect
Fuel cells	Unless economies of scale overseas or New Zealand developments result in access to cheap technology, not likely to be implemented initially, because small-scale local manufacture could not justify the cost.
Heat engines	Could be used more extensively for electricity supply using biofuels.
Small direct generation renewables	Modest support is likely to provide alternative indigenous energy supply, including efficient electricity generation from biofuels and uptake of PV.
Storage and other conversion technologies	May be needed in the longer term to address supply-demand mismatches.
Inverters and interconnection	A significant internal market for New Zealand manufacture develops, mainly for renewable energy systems initially and fuel cells later.
Manufacture of micro-scale energy technologies	Opportunity for niche for manufacture of a range of small-scale energy systems.

Economic Transformation

Economic transformation will demand substantial investment in research to adapt and change the existing electricity distribution infrastructure. Accelerated application of the technologies discussed in this section is essential to the changes in energy service delivery required from economic transformation. Of the four scenarios, research identified under demand-side generation technologies is the most relevant to this scenario.

Table 6 - Possible Effects for Economic Transformation Scenario

Subfield	Effect
Fuel cells	Development and deployment of CHP and renewable fuel systems will be accelerated (e.g. methanol/ethanol) for efficiency gains and lower GHG.
Heat engines	No significant change due to poor efficiency.
Small direct generation renewables	Strong support is likely to accelerate uptake of micro-scale renewables so they can contribute to the transformation.
Storage and other conversion technologies	May be needed in the longer term to address supply-demand mismatches.
Inverters and interconnection	A large market for these technologies develops, offering opportunity for New Zealand manufacturers.
Manufacture of micro-scale energy technologies	Opportunity for New Zealand manufacturing of a range of small scale energy systems for both local and export markets.

Energy Conservation

Energy conservation will demand much-improved supply efficiencies. Large efficiency improvements can only be achieved through distributed generation and CHP. Accelerated application of the technologies discussed in this section is essential to achieve these improvements. The proposed research in demand-side generation technologies is therefore highly relevant to this scenario.

Table 7 - Possible Effects for Energy Conservation Scenario

Subfield	Effect
Fuel cells	Development and deployment of CHP and renewable fuel systems will be accelerated (e.g. methanol/ethanol) for efficiency gains and lower GHG.
Heat engines	No significant change in use due to poor efficiency and GHG from fossil fuels.
Small direct generation renewables	Strong support is likely to accelerate uptake of micro-scale renewables so they can contribute to the conservation of traditional supplies.
Storage and other conversion technologies	May be needed in the longer term to address supply-demand mismatches.
Inverters and interconnection	A large market for these technologies develops, offering opportunity for New Zealand manufacturers.
Manufacture of micro-scale energy technologies	Opportunity for New Zealand manufacturing of a range of small-scale energy systems for both local and export markets.

D. INFRASTRUCTURE

Facilitator: Hamish Trolove, CRL Energy

D.1 Background

Infrastructure is the underlying base or foundation services and installations necessary for the functioning of a society. It is the means by which energy, materials, services, information and people can be transferred from points of source to demand. This appendix draws on the following documents:

- *People, Places, Spaces – a Design Guide for Urban New Zealand* [8];
- *Research Strategy 1999/2004* [9];
- *Land Transport Research Needs in New Zealand – October 2003*[10].

This appendix also considers all types of infrastructure which have a significant bearing on energy transmission and use, including the electricity infrastructure, transport, urban design, and infrastructure for the conveyance of fuels.

The ability for an economy to develop and respond to changes is related to the options enabled by the type of infrastructure available and the speed at which the existing infrastructure can be changed. It is essential for a healthy economy that the infrastructure is adequately designed to operate efficiently and remain flexible enough to be modified to meet changing demands – for example, in the face of increasing energy prices, a city with a strong public transport system will have more and better options than one with a non existent public transport system.

The key qualities and attributes of infrastructure are:

- infrastructure requires a large capital investment and so the structures implemented last a long time and have 'inertia' when it comes to change;
- the costs of getting infrastructure wrong are significant and long lasting;
- the number and effectiveness of solutions available are enhanced or retarded by the way in which infrastructure has developed in the past and is developing into the future;
- infrastructure needs to be adaptable to meet changing needs of society;
- infrastructure needs to be resilient so that the catastrophic failure of part of the infrastructure or

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[8] *People, Places, Spaces – A Design Guide for Urban New Zealand* published by the Ministry for the Environment in 2002. ISBN: 0-478-24049-X

[9] 'Transfund New Zealand's Research Strategy 1999/2004', as amended by the New Zealand Transport Strategy, Version 5, January 2003.

[10] 'Land Transport Research Needs in New Zealand' October 2003; Ministry of Transport; prepared by Pinnacle Research.

another type of infrastructure associated with it will not cause the entire system to fail.

New Zealand is a long and narrow country and hence our infrastructure has some atypical qualities that make it vulnerable to failure during catastrophic events, and susceptible to pressure from changing demographics. This is most applicable to the electricity infrastructure, which relies on a main trunk line to carry electricity between the islands. The major sources of supply are generally far removed from the main centres of consumption. New Zealand has a well-developed roading network but the limited rail network serves only the main centres plus a few areas where bulk commodities are produced (West Coast coal, inland Bay Of Plenty forestry). In most centres, fast-growing residential development has led to significant urban sprawl with all of the associated problems for services and pressures on infrastructure.

D.2 International Research Activities

Many countries are grappling with infrastructural problems similar to those of New Zealand and the range of research being undertaken internationally reflects this. The broad themes for international research are outlined below, but for each country the details differ, as each has a unique combination of existing infrastructure, resources, demographics, and physiography. Research done for or in any other country is not necessarily applicable to New Zealand – at least not without some careful thought about suitability and fit.

In broad terms, the following are the types of research being carried out internationally:

- studies looking at the vulnerability of infrastructure to the effects of terrorism, climate change and natural disaster(in the wake of natural disasters and terrorist activity) and developing strategies to mitigate the effects;
- investigations into the interrelationships between community and infrastructure;
- research to support development of strategies for infrastructure transformation;
- computer modelling of energy systems and infrastructure;
- research into urban form and building structures that will decrease energy intensity;
- investigating the effects of different market measures on infrastructure use – particularly congestion charging;
- impact studies looking at the effects of infrastructure on communities and the environment.

D.3 New Zealand Research

Transport infrastructure research needs in New Zealand have been outlined in the ‘Land Transport Research Needs in New Zealand – October 2003’ document but have not been examined for other types of infrastructure. Some research has been done around the nature of the infrastructure required for particular fuel types, but this has been fairly high-level and has generally ignored the wider picture of how the research will fit into the community and the environment. For the electricity infrastructure, some of the research outlined here is part of the brief of either the Electricity Commission or the Ministry of Economic Development. There is active New Zealand research into micro-grid and related distributed generation systems (refer to Section C: Demand Side: Technologies).

Background

Planning of New Zealand’s infrastructure has tended to be decentralised and to have a short-term focus; as a consequence, the integration between different types of infrastructure and the need for long-term planning to aid effectiveness has sometimes been overlooked. Economic growth has commonly been the only driver for development; environmental and social components, with their required long planning horizons and greater complexity, may not have been adequately addressed.

The government may have recognised that the transport sector cannot build its way out of problems through more roads and better intersections, for transport strategies in the public domain state that “sustainability will be paramount”. Innovation is seen as a key element to improving New Zealand’s land transport system, such that social and environmental progress is achieved rather than focusing solely on economic growth. Research will be essential to aid the understanding of the complex, less direct issues and it will be challenging to match the ideals with actions.

New Zealand Specific Issues

Energy infrastructure is specifically fitted to the country in which it exists. For this reason, most research involving the design, planning and effects of infrastructure configurations will be specific to New Zealand.

With a changing mix of energy sources being used, there will be a need to adapt the infrastructure we have at present to help efficiently distribute the available energy to the end users. To be effective, this will require a substantial amount of research to determine the optimal balance of different types of infrastructure, its form, and the likely pressures on it. Related to this is determining the optimal balance of resource use, to ensure that the many alternative demands on land (for example, for food production, recreation or environmental values) are not compromised by the need for energy production.

A key element in the transformation of infrastructure is the understanding and shifting of energy usage patterns so that energy production, transmission and use are well fitted to one other. Research into infrastructure will therefore require a component that examines the behaviour of the users and any structures influencing that behaviour.

In transforming the infrastructure or developing new infrastructure, there will be opportunities available from, and constraints imposed by, the physical, social, environmental and economic structures specific to New Zealand. Research to improve understanding of interactions will be essential for adapting existing and planning new infrastructure.

IP Opportunities
IP opportunities exist for research into infrastructure through the development of modelling and planning tools associated with the transformation of infrastructure to support new energy types (e.g., large scale bio-energy, and hydrogen) and new ways of doing things (e.g., teleworking). Tools of this nature will be essential in ensuring that investment in infrastructure is efficient and that any obstacles and constraints are predicted and dealt with appropriately. Modelling tools developed in New Zealand could have applicability overseas.

Capability Building
If an increased portion of the energy mix is to be generated from intermittent renewable sources, then New Zealand will need infrastructure capable of running efficiently despite fluctuations in supply. For the most part, it is likely that the technologies to do this will be developed overseas and it will be a matter of New Zealand becoming familiar with the technology.

Similar capability building will be required for the transport infrastructure as new design solutions and technologies are developed and implemented overseas to aid efficiencies and transformation of the transport infrastructure.

Watching Brief
Other countries will develop tools and solutions as part of the transformation and development of their infrastructure. These may be of use to New Zealand and so a watching brief should be kept on those countries whose infrastructure and mix of available energy sources resembles that of New Zealand's.

Other Activities
Consumer decision-making has a significant effect on the development of infrastructure. Altering behaviours is therefore essential for the success of infrastructure initiatives. It is likely that marketing and public awareness initiatives will be developed in parallel with the transformation of the infrastructure to help ease the way. Connections will need to be developed between the research, the marketing, and the policy-making to ensure that the right signals are being sent and that the consequences of the changes are understood.

D.4 Energy scenarios

Although each scenario will place different demands on the way in which infrastructure will develop, they all have essentially the same research needs.

Some of the broad themes that are research priorities for all scenarios are listed below, while additional priority research areas or aspects of particular importance are listed under each scenario:

Behavioural and Market Studies

- studies on the potential for performance gains in infrastructure through changes in users' behaviour and choices, and the impacts of those choices;
- investigating the interrelationships between infrastructure types and other physical, social, environmental and economic structures;
- developing techniques to encourage and promote mode changes;
- studies on the effects of changing demographics and work patterns on the infrastructure.

Planning

- investigation of the different methods of planning to gain a flexible and yet efficient planning method;
- optimised resource use – land, water — and the implications of doing this. (Where is the balance?);
- quantifying effects of good and bad infrastructural planning;
- studies, modelling and planning associated with the transformation of infrastructure to support new energy types such as large scale bio-energy, hydrogen, etc, or to revive past options such as CNG;
- developing tools that incorporate sustainability and costs of undersupply or loss of supply into infrastructure planning.

Risk Management and Future-Proofing

- contingency planning and analysis around the vulnerability of infrastructure to catastrophic failure, severe oil shortages and the long-term effects of climate change;
- development of systems to alleviate problems associated with large numbers of intermittent generation grid entry points.

Primary Industry-Led Growth
The Primary Industry-Led Growth scenario will be mainly focused on continuing economic growth and so will be looking to reinforce the existing infrastructure for greater energy transmission, economic efficiency and reliability of the supply. Research will be around maximising the efficient distribution of energy, enhancing reliability and ensuring as much energy as possible can be transferred without compromising stable operation of the energy infrastructure.

Mode change and behavioural research will not be significant programmes of research under this scenario.

International turmoil and oil supply constraints have already led to rising oil prices and price spikes. Any energy supply disruption will be a serious risk that will impact on the economic performance of primary industries. Research into the risks and contingency planning will play a big role under this scenario.

Additional infrastructure research specific to this scenario would focus on:

- technological developments associated with increasing the capacity of the electricity infrastructure;
- investigations into appropriate levels of energy storage to avoid problems with supply disruption.

Energy Security
Energy security will not be seeking to increase the quantity of energy transferred through the energy infrastructure but will be concerned with the efficient transfer of energy produced within New Zealand and the security of the system. This will require research around the optimum balance of resource use, and the transformation of the infrastructure to a more flexible and diverse system capable of reliably accepting variable inputs from a large number of grid entry points. In order to meet the energy gap left by imported oil, there will be a need to develop new transport fuels and the fuel infrastructure to cater for this.

In order to make the best use of the available energy, the transport infrastructure would require transformation towards lower energy intensity through greater use of bulk transport, rail and public transport.

Were New Zealand to provide for its own energy requirements, it would not be affected by international events causing disruptions to the energy systems, but it would require studies and contingency plans to mitigate the effects of local natural disasters and events on the energy infrastructure.

Additional infrastructure research specific to this scenario would focus on:

- research to promote mode change in transport;
- investigations into the vulnerability of infrastructure to natural disasters and the consequences of short-term catastrophic loss of energy supply.

Economic Transformation
The infrastructure for the Economic Transformation scenario is likely to undergo a significant transition as it begins to accept energy inputs from more distributed and variable sources. As heavy industries are likely to disappear under this scenario, more power will be available for the development of lower energy intensity industries. This means that the locations of the energy users will be more distributed and so require a different arrangement of the energy infrastructure.

Market measures will be the key to the transformation and so there will be significant research around the development of policies and market tools designed to bring it about.

Additional infrastructure research priorities specific to the Economic Transformation Scenario:

- Development of market tools to aid transformation to less energy intensive industries and transport mode choices;
- Development of a robust energy infrastructure that incorporates a significant amount of distributed generation and distributed end users.

Energy Conservation
It is likely that the electricity infrastructure associated with the Energy Conservation scenario is going to be of a similar capacity to the present-day, but it will be obliged to accept widely distributed points of supply, of which a large number will be variable. Research around grid stability will be important.

Changed consumer behaviour will be required. Social research to support the changes and determine the consequences of behaviour shifts will be a key element. Infrastructure will be adapted or changed as energy use patterns change. Modelling and planning the interactions between behaviour change and infrastructure development will facilitate the transition process.

As this scenario places a far greater emphasis on the use of renewable energy than all of the others, it will require the planning and development of new infrastructure to transfer new fuel types and adapt existing infrastructure to lower energy intensity.

Additional infrastructure research priorities specific to the Energy Conservation scenario are:

- research around techniques and strategies for encouraging mode change and promotion of mode change – quantify the benefits;
- understanding the interactions between consumer behavioural changes and the present and future development of infrastructure. This is particularly important for transport infrastructure and urban design;
- research to identify and model the optimum balance of resource use and the consequences of achieving such a balance. This will ensure that the development of energy generation and consumption is carried out in such a way as to be socially and environmentally sustainable.

E. BIOENERGY

Facilitators: Ralph Sims, Massey University and Hamish Trolove, CRL Energy

E.1 Background

The biomass resource is broad and includes forest products, wood process residues, animal wastes including sewage, crop residues, municipal solid waste (only the organic components) and industrial organic wastes. In addition, a range of annual and perennial energy crops can be grown specifically to produce biomass feedstock for a range of uses. Energy carriers from biomass include methane gas produced as 'biogas' by anaerobic digestion from wet wastes and landfill gas, bioheat, bioelectricity (and cogeneration of both), liquid biofuels and even hydrogen. Using a wide range of conversion technologies, bioenergy can be produced from the biomass resource to provide all forms of useful energy services. In addition, biomass can be a useful feedstock for biomaterials and biochemicals, often with a bioenergy co-product. Thus, the area of 'biomass research' can encompass a wide range of resources, their assessments, costs and potential for energy conversion technologies as well as the logistics of harvesting, storing, transporting and processing the raw biomass feedstock material.

E.2 International Research Activities

Biomass Resource Assessments and Development
Many research projects have been and are being carried out on assessing biomass resources and their delivery costs. Security of supply and the reduction of delivery costs are the main aim of the activities. Research in developing more efficient and more tolerant crops are carried out around the world.

Development of Technologies - Converting Biomass into Heat and/or Electricity
There exist many different technologies to convert biomass into heat and/or electricity. Some systems have been used for decades and some are still under development. Typically also the kind of large systems which prevail have been developed due to economy of scale advantages. With a changing energy sector scene, small-scale systems and distributed generation systems are becoming more viable, which in turn has seen these activities become the focus of an increasing research and development effort.

Development of Technologies-Converting Biomass into Liquid Biofuels
A significant amount of research is going on in this area around the world. The focus has been on converting non-woody biomass crops. However, the recent increases in world oil prices have stimulated support for projects converting all kinds of biomass resources into liquid biofuels.

Market Development-Policy Analysis-Demonstration
The flexibility and multi-faceted aspects of bioenergy technologies make modelling and early assessment of new technologies very important. In many countries, policies around the implementation of renewable energy systems have been supported by demonstration programmes. These are used both to demonstrate imported and domestically manufactured technologies and to stimulate uptake of new, advanced technologies. It is also to support domestic technology development. When a bioenergy programme is introduced in Europe, its potential impact on the economy is researched using advanced modelling.

E.3 New Zealand Research

New Zealand has a unique set of biomass resources which differ from other nations, distinguished by factors such as their origin, the distinct farming and forest systems, soil types, moisture content, distribution, related land use, water availability, population density, nature of the food and fibre industries etc. Thus any resource assessment has to be conducted locally. Similarly, imported bioenergy conversion plants will need to be evaluated locally based on the specific effects of the New Zealand biomass resource. For example, even co-firing of small quantities of woody biomass with coal can have effects on the combustion process and ash production which are unique and which differ from experiences of using biomass elsewhere.

New Zealand is mainly a technology taker in this area. Many overseas technical solutions for processing biomass and bioenergy conversion would have immediate application. However, even for a relatively mature technology such as landfill gas utilisation, a gas engine may work successfully but the volumes of gases may differ as well as their corrosive properties. For this reason, demonstrations of bioenergy projects which are fully monitored and measured, and with the results publicly available, are often useful to provide confidence in the technology and hence to gain more rapid implementation and replication.

The markets for bioenergy vary with region and type of energy service, but in all cases they are not clearly defined. The current dearth of long-term national and regional policies, the kind of legislation and regulation possible, along with other mechanisms relating to greenhouse gas emissions, water allocation, transport fuels, vehicle exhaust emissions and so forth does not create any certainty for future investment, which in their absence remains risky for businesses to contemplate. The costs of various sources of heat, power and vehicle fuels are often based on simple comparisons rather than using a full life-cycle analysis which includes valuing all the co-benefits. Already many biomass projects using 'waste' products are viable yet large volumes of the cheapest biomass resources (in terms of \$/GJ delivered) are still being dumped into landfills or not collected at all. Other biomass ‘waste’ products are competing with bioenergy applications for use as building materials. In the longer term, the development of biomass processing ‘refineries’ to provide a range of products and services (such as polymers, biofuels and electricity) needs evaluation.

New Zealand-Specific Issues

Project development differs from case to case, but some aspects show commonalities between projects. These include securing long-term biomass supplies of appropriate quality, and the resource consenting process under the RMA, including possible air and water emissions, road transport impacts, plant location etc. As has been successfully achieved elsewhere, a set of industry ‘best practice guidelines’ for each major biomass sector, discussed and approved by all stakeholder groups, could enable more rapid project uptake to occur.

Future land use change should be evaluated due to world oil price fluctuations, uncertainty of natural gas supplies, the exchange rate, the implementation of carbon trading, etc. The opportunity to integrate food and fibre production better with biomass production for energy in plantation forests, arable crops, the animal product industries, horticulture (e.g. producing bioethanol from reject kiwifruit) needs closer assessment. Sustainable land use, including water uptake, nutrient recycling, carbon sequestration (which means both biological, as well as linked with geo-carbon, capture and storage), together with the related major social implications for future rural communities all warrant detailed evaluation.

The use of biofuels in vehicle engines has long been understood (since the Liquid Fuels Trust Board days of the 1970s and 80s). The current vehicle fleet consists of a wide range of makes and models, many being second-hand imports. Thus the level of suitable blends of bioethanol in petrol and biodiesel in diesel needs further evaluation. There will also be the opportunity for New Zealand to both import biofuels and/or export biomass feedstocks. World trade in biomass has begun and the IEA (International Energy Agency) has established a new activity within the Bioenergy Agreement on the topic. Importing bioethanol from the Fijian sugar industry is an example.

In summary, the development of a new biomass and bioenergy industry could play to New Zealand’s strengths as a primary producing and processing nation based around efficient land use, good soils and enviable climatic growing conditions. Regardless of the medium- to long-term future of the planet, it would make sense to utilise the existing biomass resource to a greater degree, and possibly enhance it with energy cropping, to provide greater security of energy supply, help meet Kyoto Protocol obligations and provide a wide range of social benefits including health, employment, and support for rural communities etc. A full analysis of the benefits, barriers and demerits (rather than just undertaking a simple cost/benefit analysis) is warranted. In the longer term, GM processes for bioenergy production after a long period of laboratory testing may have application, but whether GM resources are used or not, the production and utilisation of biomass in a sustainable manner to produce renewable bioenergy needs careful evaluation.

IP Opportunities

IP possibilities range from the breeding of new crop strains and short-rotation forests etc. suitable for energy cropping to the development of efficient and small-scale bioenergy conversion plants. Currently, a range of manufacturers of innovative small domestic to large industrial wood combustion plants show how Kiwi ingenuity will flourish given the right opportunities and incentives. Ligno-cellulose to bioethanol is one such area of great potential, linking the biotechnology and agricultural industries.

Capability Building

The forestry and agricultural industries have identified many novel approaches to technology development, methods of production, resource handling, storage and processing etc over the past few decades to ensure New Zealand has remained to the fore as an exporter of high-quality food and fibre products. This has resulted from continued education and research, development and demonstration (R, D and D) investment in the primary and secondary industries. A similar approach is needed for biomass and bioenergy to build on this existing capacity and to anticipate the de-carbonised world of the future.

New Zealand will remain a technology taker in many areas relating to all renewable energy systems, but there are good opportunities to develop local biomass/bioenergy solutions in particular, based on our current experience and world leadership in the field.

Watching Brief

New Zealand is a member of the IEA Bioenergy Agreement, IEA Hydrogen (which includes biomass feedstocks), the International Partnership for the Hydrogen Economy, several bilateral research collaborations and other informal biomass co-operation activities such as the IEA Bioenergy Socio-Economic Activity. Input into these international activities resulting from a relatively low R, D and D investment produces access to highly funded programmes from many other countries. These activities should be continued and expanded – but with the industry’s Bioenergy Association of New Zealand (BANZ) providing appropriate personnel to attend meetings and report back to all members from time to time.

Other Activities

The New Zealand public is largely unaware of the major contribution to consumer energy that biomass has long provided. They are unaware of the market and socio-economic potential for bioenergy, the health benefits that can accrue (such as lower particulate emissions from diesel engines), the potential biomass holds for providing energy security in this uncertain world, the clean and modern technologies that exist to provide a wide range of energy services from this resource, or even how best to operate a domestic wood stove. The image of using biomass for energy purposes is poor and needs improving if bioenergy projects are to make a greater contribution to the New Zealand energy mix in the future.

E.4 Energy Scenarios

Bioenergy has been identified as having a high relevance to all of the scenarios, particularly with regard to transport fuels and energy security. However, each scenario places a slightly different emphasis on which parts of the bioenergy field are important. For the sake of avoiding repetition, the common elements to all scenarios are listed below and scenario-specific research areas or research areas that are a variation of the common theme are listed under each scenario.

Some of the broad themes that are research priorities for all scenarios are:

- demonstration of bioenergy plant and techniques of different types to promote familiarity with the technology and generate confidence amongst the public and industry. Of particular importance are demonstration projects making use of biomass cogeneration for heat and electricity;
- investigating cost-effective means for the collection, transportation of biomass, and its conversion to liquid biofuels;
- detailed analysis and assessment of the bioenergy resource;
- reviewing and updating the previous research carried out by the Liquid Fuels Trust Board;
- investigations into the synergies for grouping multiple biomass processes together on one site; combustion, gasification, pyrolysis, fermentation and burning;
- making use of New Zealand's strengths in bio-sciences by developing bioenergy crops based on indigenous or exotic species that are suited to New Zealand's conditions, and investigating the economics of growing and processing them;
- investigations into the relative economics of the different uses for biomass; energy production and materials production;
- research into the effects on the environment of bioenergy cropping;
- research into the use of pyrolysis char for soil improvement and bio-sequestration;
- research to support the introduction of biorefineries;
- development of techniques for upgrading biomass to aid its transportation: e.g., drying and on-site pre-processing;
- research to find the balance of land use and water use for energy production, food and fibre production, biodiversity, and recreation;
- investigations into public perceptions and understandings around the use of bioenergy and the effects it will have on society;
- research into the effects of bioenergy on society, the economy and the environment.

Primary Industry-Led Growth
The emphasis of bioenergy research under this scenario is upon ensuring bioenergy collection and processing costs are kept down and upon the economic implications of using bioenergy on a large scale. Development of bioenergy will be partly driven as an insurance measure to protect New Zealand's industry from energy price fluctuations imposed by international fossil fuel prices. The major technological research and development will be conducted outside New Zealand and so New Zealand will mostly be a technology taker.

New Zealand bioenergy research specific to this scenario would focus on:

- investigations into accessing low-cost biofuels from overseas sources;
- development and demonstration of liquid biofuel plants for bioethanol and biodiesel using lactose and tallow as the feedstocks in the first instance.

Energy Security
Bioenergy has a very high relevance to the Energy Security scenario as it is one of few full or partial solutions to problems with the supply of liquid transport fuels that can reliably be counted upon to yield positive outcomes, and that can be accomplished entirely within New Zealand. With a worldwide shift to putting a high priority on energy security and trade protectionism, there will be a corresponding decrease in New Zealand's ability to sell its dairy and forestry products to foreign markets, leading to large quantities of biomass and land becoming available for bioenergy development. Under this scenario, there is a much greater need for research and the development of bioenergy-related skills and technologies within New Zealand, to make up for the decreased ability to import the necessary bioenergy equipment and skills.

Bioenergy research priorities specific to the Energy Security scenario are:

- research to accelerate the development of an efficient bioenergy infrastructure;
- development and demonstration of transport biofuel plants for biogas, bioethanol and biodiesel using

biomass, organic waste streams and dedicated crops as the feedstocks;

- investigations into the full economics of both large centralised and small decentralised biomass plant for producing heat, electricity or biofuel products;
- developing multi-fuel capability in commercial buildings and industrial sites to promote energy security;
- research to investigate the full impact on the economy, society and the environment of a large-scale bioenergy industry, in terms of land use, water use, biodiversity, employment, community vision, public health, and general public understanding of how much energy the country uses;
- investigations into the relative economics of the different uses of biomass, land, and water for energy production, food production, materials production, and recreation;
- development of mobile biofuel production plants;
- development and demonstration of bioenergy solutions for isolated communities;
- development and demonstration of on-farm biogas generation for electricity, heat, and transport fuel.

Economic Transformation

The Economic Transformation scenario makes use of market tools to aid the transition to a more sustainable energy future. Because of this, it requires much greater understanding of the way people and markets behave and how they will react to the introduction of a large bioenergy industry.

Bioenergy research priorities for the Economic Transformation Scenario:

- development and demonstration of transport biofuel plants for biogas, bioethanol and biodiesel using organic waste streams and biomass as the feedstocks;
- investigations into the full economics of both large centralised and small decentralised biomass plant for producing heat, electricity or biofuel products;
- research to investigate the full impacts on the economy, society and the environment of a large-scale bioenergy industry; in terms of land use, water use, biodiversity, employment and health.

Energy Conservation

The energy conservation scenario seeks to achieve full sustainability and hence eliminate fossil fuels from the energy mix. This means that there is a large gap in the energy mix left by the absence of coal and fuels derived from fossil oil. Bioenergy is the most suitable energy form to take their place. In the energy conservation scenario, there is therefore a strong need for research to develop the technology and aid the uptake of bioenergy. In addition to this, there will be a need for societal change to make the most efficient and effective use of the renewable energy mix.

Bioenergy research priorities for the Energy Conservation scenario are:

- research to accelerate the development of an efficient bioenergy infrastructure;
- development and demonstration of transport biofuel plants for biogas, bioethanol and biodiesel using biomass, organic waste streams and dedicated crops as the feedstocks;
- investigations into the full economics of both large centralised and small decentralised biomass plant for producing heat, electricity or biofuel products;
- developing multi-fuel capability in commercial buildings and industrial sites to aid energy security;
- research to investigate the full impacts on the economy, society and the environment of a large-scale bioenergy industry; in terms of land use, water use, biodiversity, employment, community vision, public health and general public understanding of how much energy the country uses;
- investigations into the relative economics of the different uses of biomass, land, and water for energy production, food production, materials production, biodiversity and recreation;
- research into the use of bioenergy processing wastes for soil improvement and bio-sequestration: e.g., digester sludge, pyrolysis char, gasifier ash and fermentation must;
- development of mobile biofuel production plants;
- life cycle analysis of all materials within New Zealand and the comparison with wood and biorefinery products;
- development and demonstration of bioenergy solutions for isolated communities;
- development and demonstration of on-farm biogas generation for electricity, heat and transport fuel.

F. SOLAR

Facilitators: Dr A Bittar and Mr A I Gardiner, Industrial Research Limited

Energy from the sun is the most abundant energy resource. It is practically inexhaustible. Solar energy is distributed across the globe. Solar energy is sufficient to supply 10,000 times the world's energy needs. However, solar energy intensity has a relatively low peak of around $1kW/m^2$. Total solar energy intercepted by New Zealand land mass is approximately $1.4x10^6$PJ/yr. New Zealand's total consumer energy demand in 2003 was 515PJ or less than 1/3000 of this. A New Zealand house receives approximately 25 times its typical needs from solar radiation. New Zealand's insolation levels are similar to those of Melbourne, Australia but about 1.4 times those of Central Europe.

Use of solar energy requires:

- knowledge of the resource;

- development of appropriate technologies for conversion to useable form.

F.1 Background

There is historical knowledge of the solar irradiance at a number of sites across New Zealand at hourly, daily, seasonal and yearly intervals. These sites cover areas of high population density. The information is sufficient to enable design of most technology conversion systems envisaged at those sites. There is little detailed knowledge outside those sites: e.g., in rural New Zealand.

F.2 Solar technologies

Numerous technologies exist to convert solar radiation to heat, electricity and fuel.

Solar Heat

Solar thermal conversion systems are the oldest, most advanced and economical solar conversion systems. They take the following forms:

- flat-plate systems operating at temperatures up to 70ºC: useful for solar swimming-pool heating and solar domestic hot water applications. This is mature technology in use in New Zealand. It is cost-effective, but needs greater market adoption;
- evacuated tube systems, with highly selective coatings can reach temperatures of >200ºC. This is a developing technology and new system designs would allow coverage of commercial and industrial heat requirements;
- solar thermal-electric (STE) power plants are the only large-scale commercial solar electricity generation technology implemented to date. They are viable in very high insolation areas only. A commercial plant is in operation in the USA; and several demonstration versions are implemented in the USA, Spain and Australia.

Solar Electricity

Photovoltaic (PV) devices use semiconducting materials to convert sunlight directly into electricity. Most are made of silicon and have efficiencies of up to 20%. Cost considerations currently make these economic as diesel replacement in remote areas, consumer products and stand-alone applications for telecommunications. Prices are around US$5/Wp and dropping with a progress ratio of around 0.8. They are near-commercial in grid-connected situations, and are expected to be cost-competitive with central generation globally when prices drop to US$1/Wp. Significant, grid-connected penetration is expected in high-cost electricity markets over the next decade. PV systems generally require an inverter to interconnect the variable, low voltage DC output to grid-quality AC power, which adds significantly to the overall system cost. Inverters are now very sophisticated with built-in maximum power point tracking and protection, and can have efficiencies of 90%+ over a wide power range.

Major solar-electric types are:

- C-Silicon, poly-Si (90% of market);
- thin-film a-Si, CdTe, CIGS and others ~10% of market;
- dye-sensitised cells.

Solar fuels

Solar production of fuels has been mostly aimed at hydrogen production using high temperature direct thermal water splitting and photoelectrochemical conversion using semiconductor junctions. For direct thermal water splitting, temperatures of 2000ºC or more are required, which are produced by very high concentration solar systems Thermally assisted electrolysis requires 1000ºC or more. At these elevated temperatures there are significant issues associated with materials, thermal effects and corrosion to be overcome. Photoelectrochemical systems operate at room temperature, but the combinations of chemical and physical processes are complex, and new materials are required to improve efficiency and lifetime. More recently, attempts to couple solar-electric and wind-electric systems to electrolysers have been trialled successfully.

F.3 International Research Activities

Globally, solar energy is identified as a key resource for future energy supplies.

Solar hot water is largely a mature renewable energy technology. Research efforts are now mostly focused on product and market development activities, to encourage industry development and create public awareness and acceptance of this technology. Production growth is being fuelled by market incentives in many countries. Growth will continue to be driven by reduction in installed costs through standardisation of installation methods and increasing production volumes.

Photovoltaics (PV) are the key photoelectric energy technology poised for massive long-term growth. Reduction in cost is occurring through the simplification of manufacturing methods and production economies of scale. Strong research efforts continue in the quest for more cost-effective conversion techniques, including novel, multi-junction devices for higher efficiency and to improve thin film devices for lower cost and longer life. The impressive market growth of between 30-40% per year is expected to continue as photovoltaics start to penetrate the conventional grid supply market in many countries, with full commercial competitiveness expected to occur around 2010-2015.

Key Research Issues

Commercial/Industrial Solar Thermal
Applications research is required, as is improved systems technology for commercial and industrial solar heat capture and integration.

Network PV Generation
Photovoltaic materials research is continuing, to increase efficiency and lower costs. Applications and system integration research is needed into how to manage the substantial impact these technologies will have on the existing electricity supply infrastructure, and improve the overall efficiency of the PV conversion system.

Hydrogen Fuel Production
Longer-term research on feasible and cost effective direct solar hydrogen production methods, to replace conventional hydrocarbon fuels with direct solar energy synthesised alternatives. Commercial processes are expected 2015-2020.

F.4 New Zealand Research

New Zealand Specific Issues

At present the solar resource in New Zealand is known quite well in the main centres but has not been quantified in detail elsewhere. In order to enhance the widespread uptake of solar technologies the resource needs to be better understood in those places where solar technologies will be of particular benefit, such as in rural and other remote locations. A key research area is to extend the existing resource data and models to cover all locations in New Zealand and in particular make access to data on the performance of solar technologies throughout New Zealand readily accessible.

To accelerate the uptake of solar technologies, tools and databases to assess the potential of industrial and commercial sites to benefit from solar technologies for heat and solar electricity, need to be developed. Novel, cost reducing designs for commercial and industrial solar thermal systems working at intermediate temperatures are needed.

At present there are no examples of medium- to large-scale solar technology in use around New Zealand other than on some municipal swimming pools. Demonstrations of mid-scale industrial and commercial solar heat systems will provide opportunities to learn the technology and create confidence in the technology.

To obtain value in the New Zealand context from these, the technological developments, policy and market measures need to be developed and implemented to ensure the adoption of existing and new solar technologies into industrial and commercial sites. Similarly policy and market measures will need to be developed to aid the large-scale implementation of residential and small commercial photovoltaic systems.

Local demonstrations of large-scale, grid-tied urban photovoltaic systems will enhance their uptake in the main centres around New Zealand as well as build skills and expertise that can be exported.

Research to develop or adapt the technologies and control systems to allow large-scale connection of photovoltaic systems to the existing electricity infrastructure is required as an essential step in enabling more solar energy to be used in all sectors.

IP Opportunities

IP will be generated in the development of tools and databases to assess the potential for solar energy in New Zealand industrial and commercial sites. The expertise and capability built up will be applicable to overseas sites.

IP can be generated through research that produces tools and systems to dynamically measure the solar resource via satellite imaging. This will be important for the future development of predictive/control mechanisms for the implementation of large-scale solar energy power plants.

Development of the cost-effective balance of system components such as inverters and storage systems has the potential to produce valuable IP.

Capability Building

Development of tools and databases to assess the potential of industrial and commercial sites to benefit from solar technologies for heat and solar electricity, will help build the capability, skills and techniques required to aid uptake of the measures in the commercial and industrial sectors.

Construction and operation of demonstration systems as outlined in the New Zealand-specific issues section above will help build capability and familiarity with the solar technologies involved.

By being involved with overseas research and development of solar technologies such as advanced evacuated-tube-based thermal systems for commercial and industrial applications, thin-film silicon cells, poly-silicon on glass, new semiconductors (Group III Nitrides, polymers, absorbers) and new structures (multi-layers, quantum dots, new dyes, organic materials), New Zealand can develop the skills and capabilities that will allow it to quickly adopt and adapt the technologies as they become available.

Watching Brief

Solar technologies will play a role in the development of the hydrogen economy, as a carbon free method of generating the fuel. Several promising methods in development internationally are:

- solar PV + electrolyser for early-phase distributed hydrogen fuel production;
- photoelectrochemical cell (PEC) systems offering higher efficiency and cost reduction;
- photocatalytic systems - higher efficiency and cost reduction;
- development of low-temperature solar processes for splitting water to produce hydrogen.

As New Zealand has established expertise in material sciences and chemistry, it has the potential to take on these research areas quickly if the hydrogen economy begins to look like a reality.

Other Activities

A bottleneck has arisen in the production of cost-effective photovoltaic systems due to difficulties producing silicon. At present, most of the silicon for the PV industry is reject material from the computer industry and so is not produced in large enough quantities and is of a higher grade than is required. It is therefore crucial for the widespread implementation of photovoltaic systems that cost-effective, high-volume silicon feedstock production technology is developed. However, New Zealand is unlikely to contribute to addressing the solutions, which involve extremely high investment costs.

Within New Zealand, near-term uptake of solar technologies will require recognition of the broad environmental and societal benefits of introducing a more sustainable energy system. These benefits will need to be paid for by the public at large through regulatory support and early adopter benefits.

F.5 Energy Scenarios

Uptake of solar energy is relevant to all of the proposed scenarios. The contribution of solar energy to all scenarios is substantial in the long term as it is an inexhaustible supply of clean energy and solar electric power will continue to become more cost-effective through to at least 2050. Solar thermal energy can be stored in a variety of ways, the most common being as hot water for direct use. However, solar PV electricity cannot be fully dispatched. Accordingly, solar electricity will have a limited market share until appropriate secondary storage systems are introduced. There are many possible options available, but any solution will involve additional cost, and will be dependent on the relative importance placed on renewable/indigenous resources under the specific scenarios below.

Solar heat has the potential to displace approximately 730GWh/yr of current residential electricity use under all scenarios (and an equivalent amount is possible for industrial/commercial). The degree and speed of uptake will depend very much on government commitment to accelerating the development of a fully sustainable energy system.

Primary Industry-Led Growth

In this scenario, the demand for lowest-cost energy is high. It is unlikely that in the short to medium term, the higher initial cost of solar PV energy will be attractive under this kind of economic driver. Solar thermal uptake will require continued support.

Energy Security

Solar PV and thermal energy will both need to be encouraged as they will reduce dependence on imported hydrocarbon fuels. Indigenous development of electric vehicles and regulatory action may drive the development of a relatively high-cost but renewable fuel transport infrastructure for local-trip vehicles, to reduce oil dependency. Priorities could be the development of effective market and regulatory mechanisms to aid and accelerate uptake of PV and solar thermal.

Economic Transformation

Solar PV and thermal energy should be encouraged as they support transformation to a sustainable infrastructure, but at a high initial price. A priority is for high-value energy products such as inverter technologies and solar systems to be promoted via manufacturing development instruments, to replace energy-intensive sunset industries. Internal market incentives should be created to encourage manufacturing growth and drive down prices.

Energy Conservation

Solar PV and thermal energy should be encouraged as they reduce dependence on scarce imported hydrocarbon fuels. Priorities could be the development of effective market and regulatory mechanisms to aid and accelerate uptake of PV and solar thermal.

G. WIND

Facilitator: Hamish Trolove, CRL Energy

This section has been written with help and advice from the Centre for Advanced Engineering, EECA, and Meridian Energy, and draws on the document Manufacturing Opportunities from the New Zealand Wind Farm Industry: A Study for Industry Capability Network New Zealand[11]. This section is mainly concerned with the research associated with wind turbine technology and resource as associated research into infrastructure and distributed energy systems are covered in other sections.

G.1 Background

Wind energy development worldwide has reached the growth stage in its 'product life' and is seeing a massive expansion of generation capacity. In 1992 there was

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[11] 'Manufacturing Opportunities from the New Zealand Wind Farm Industry: a study for Industry Capability Network New Zealand' Energy Information Services Ltd, Wise Analysis, August 2004

2500MW of capacity installed globally. In 2003 global installed capacity exceeded 40GW. Annual global growth in capacity is approximately 30% per year with total installed capacity projected to top 150GW by 2010[12]. Research on the development of improved wind turbines and on support for installation and uptake is being done in many countries.

New Zealand is also experiencing a massive growth in installed wind energy capacity as the economics become favourable and the results of some of the government's initiatives[13] to aid investment and development of renewable technologies come to fruition. In March 2005 the total installed capacity of wind turbines was 166MW[14], with growth conservatively projected to reach 634MW installed capacity by 2025[15].

Wind energy technology has an advantage over most other forms of electricity generation in that wind turbines can be erected quickly and with minimal environmental impact. Since electricity generated from wind requires no fuel, generates no waste and emits no greenhouse gases, it is an environmentally benign form of electricity generation, apart from the visual impact on landscapes. Despite this, one of the main barriers to implementation is the 'not in my back yard' phenomenon that is particularly prevalent within New Zealand.

New Zealand's geographic position has given it one of the best wind resources in the world, with annual average wind speeds of the order of 10 m/s in a number of sites. However the nature of the terrain means that some sites are likely to be subject to turbine load-related issues.

G.2 International Research Activities

There is considerable research effort around wind energy internationally looking at all aspects of the technology and its implementation. Some of the key research needs identified are:

- development of better aerodynamic models, materials and generators, so as to drive down the costs, and improve the performance, of the turbines;
- development of intelligent controls and associated wind turbine modelling to aid integration of wind generation into the electricity infrastructure;
- diminishing environmental impacts through multiple land use, visual integration, noise control and flora and fauna impact studies;
- development of forecast systems and hybrid systems (i.e. complementary wind turbine and natural gas generator sets);
- development of energy storage systems which can be closely integrate with wind energy generation;
- development of standards and testing for wind sites and turbines
- resource assessment;
- improved power quality and integration of large scale systems with electricity grids;
- reliability and maintenance improvements.

G.3 New Zealand Research

New Zealand has very limited wind energy technology development at present, with most research attention focused on developing wind resource models and surveys. Typically, wind energy generator technology is purchased from overseas developers for installation on New Zealand sites. One local manufacturer (Windflow Technology Ltd) is still at the field trial stage of product development.

New Zealand-Specific Issues

Although New Zealand is a technology taker for wind turbines, some areas of research specific to New Zealand should be pursued to aid the uptake, integration and acceptance of wind energy technology. These include:

- aiding integration of wind energy with the electricity grid through the development of models and standards, covering both large- and small-scale wind generation;
- development of siting solutions to aid visual integration of wind turbines into the surroundings and thereby reduce their visual impact;
- development of models to forecast real-time generator output up to 6 hours in advance;
- addressing the issue of 'not in my back yard' through moderating the effect of wind turbine development, mitigating the risks or educating the public about perceived risks and the advantages of wind energy;
- research and development to identify and trial compatible activities for multiple land use.

IP Opportunities

New Zealand has some key strengths that could potentially generate intellectual property that may be of value both within New Zealand and internationally, including:

- research and development of composite materials and techniques for the manufacture of wind turbine components;

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[12] 'Needs for Renewables - Developing a New Generation of Sustainable Energy Technologies', IEA, Oct 2000

[13] 'Projects to Reduce Emissions', New Zealand Climate Change Office

[14] 'New Zealand Energy Data File', Ministry of Economic Development, July 2005

[15] 'New Zealand Energy Outlook to 2025', Ministry of Economic Development, October 2003

- development of models for forecasting real-time generation output up to 6 hours in advance to aid optimised operation of the grid and other types of generation;
- techniques and technologies for operating wind turbines on turbulent sites or those sites where the wind resource is erratic.

Capability Building
As more wind energy technology is developed within New Zealand, so more skills and expertise will be required in order to make the best use of it, such as:

- manufacture and techniques for wind turbine components using composite materials;
- developing capability in intelligent control technologies for wind turbines and the interaction of large-scale wind turbine developments with the electricity grid.

Watching Brief
Almost all of the technology for wind turbines and generators will be developed overseas but New Zealand must keep abreast of developments in what will be a rapidly changing field. Areas of overseas research that should be monitored include:

- improved aerodynamic models of wind turbines, more efficient generators, and quieter and more efficient turbines;
- development of hybrid systems.

Other Activities

- Studies of the effects of wind developments on flora and fauna around wind sites may help mitigate opposition.

G.4 Energy scenarios

There has been rapid growth in the installed wind farm capacity in New Zealand and the growth is set to continue for at least the next twenty years. The highest-priority wind-related research needs for New Zealand are in aiding the integration and acceptance of wind energy solutions.

Primary Industry-Led Growth
The focus for Primary Industry-Led Growth is on an affordable and available energy supply and as such, the intermittency of wind energy makes it a lower priority as an energy resource. Research priorities for wind energy under this scenario relate mainly to the integration of wind-generated electricity into the electricity infrastructure without compromising the system availability.

Energy Security
Under this scenario New Zealand seeks to maximise its energy security through maximising the use of New Zealand's indigenous renewable energy sources, and implementing strong regulatory structures in order to achieve this.

The research priorities are:

- complete assessment of the available resource and the identification of the sites of different quality;
- research and development of techniques and technologies for the manufacture and repair of wind turbine components from advanced composites;
- developing systems and models for integrating wind energy into the grid and its interaction with other generation types;
- techniques and technologies for operating wind turbines on turbulent sites and those sites where the wind resource is erratic.

Economic Transformation
Under an Economic Transformation scenario, distributed energy will play a large role; consequently there will be considerable development of wind generation capacity. There will be less of a need for New Zealand to 'go it alone'; technology will be bought in from overseas. The research focus for wind energy in New Zealand will be:

- refinement of the energy resource models and identification of sites;
- integration of large- and small-scale wind energy into the grid and making the best use of the storage present in other forms of energy, through predictive modelling and the development of standards;
- developing familiarity with intelligent control systems for wind power;
- addressing the issue of 'not in my back yard' through moderating the effect of wind turbine development, mitigating the risks or educating the public about perceived risks.

Energy Conservation
Under the Energy Conservation scenario, there is a strong drive to replace all fossil fuel generation with renewable energy. Under this scenario, a large part of New Zealand's energy needs will be met through the use of wind energy.

Research priorities under this scenario will be:

- aiding integration of wind energy with the electricity grid through the development of models, covering both large- and small-scale wind generation, and the effective use of energy storage through other energy forms;

- development of schemes that appropriately site wind turbines to aid their visual integration into the surroundings and thereby reduce their visual impact;
- development of technologies and techniques for reducing or mitigating the noise of wind turbines;
- development of models to forecast real-time generator output up to 6 hours in advance so as to optimise the use of the available generation mix;
- addressing the issue of 'not in my back yard' through moderating the effect of wind turbine development, mitigating the risks or educating the public about perceived risks and the advantages of wind energy;
- research and development to identify and trial compatible activities for multiple land use;
- developing capability in intelligent control of wind turbines and their interaction with the electricity grid;
- techniques and technologies for operating wind turbines on turbulent sites and sites where an erratic wind resource is present.

H. OCEAN AND HYDRO

Facilitator: Murray Poulter, NIWA

H.1 Background

With the strong global push towards renewable energy, attention is again focusing on as-yet untapped marine sources. These are estimated to be a significant resource for New Zealand, but remain unexploited due to costs associated with the development of efficient extraction devices and operation in the marine environment. There is increasing interest worldwide with many research and development projects being supported, but as yet no technology that is (economically) competitive. Of interest to New Zealand are wave energy and tidal stream energy. Key requirements are useful energy conversion efficiencies and robust operation in the demanding ocean environment. For wave devices, this includes a wide range of wave energies, corrosion, fouling and appropriate construction and mooring technologies. Tidal stream technologies have to contend with the same deployment and operating issues, but with a predictable range of generally low flow speeds without wide extremes. Barrier type designs are not favoured due to their potential environmental effects and the relatively low tidal range around New Zealand.

It is interesting to consider hydro and marine together, since they represent the opposite - mature and emerging - ends of the development spectrum. Hence the marine area may present significant opportunities, supported by New Zealand's active marine engineering sector. Marine and hydro sources benefit from the high total energy availability for New Zealand and also from the energy density inherent in energy sourced from water mass. New Zealand has a high renewable component already, based largely on hydro resources. The flexibility and storage associated with hydro generation is required to balance the other renewables with their dependency on variable weather and climate time scales and their negligible direct storage options. Integration of a range of variable generation at different locations will be an operating requirement. Remote community power generation may offer advantages for wave energy, especially for Pacific Island states.

H.2 International Research Activities

The potential of wave energy has long been recognised. After a flourish in the 1970s, research and development effort languished. This situation is now being reversed with significant research underway, largely in Europe with some co-ordination under EU Framework 6. Initiatives range from well-funded research programmes to the work of enthusiastic individuals, characteristic of an immature field, with leaders but no clear winners at this stage. Much effort is focused on the development of devices to extract wave and tidal stream energy, since these will compete in the global market, whereas related research into resource, implementation and impact is local in nature. Tidal stream devices are focusing on 'wet' windmills, both horizontal and vertical. Wave energy, on the other hand, has a much wider range of devices under development, using wave motion, water pressure and related air pressure. The first commercial wave energy devices are currently being installed off Portugal (Ocean Power Delivery's Pelamis device, 2.25MW initially), and a marine stream turbine trial is taking place off Northern Ireland (Marine Current Turbines Ltd). Getting devices off the drawing board is a priority research area.

For hydro, the technology is mature and international research effort is focused on operational issues, looking at performance and production (improved turbine design, fish-friendly turbines, turbulent flows and structures), environmental issues including protocols for measuring mitigation, and innovative operations: i.e., better integration with flow, sediment and environmental constraints.

An emerging research area considers coupled or linked generation technologies, for example evaluating wind (or wave or tidal stream) production profiles to determine hydro requirements for load-following, to understand the system impact of a wide range of variable and distributed inputs, on a central system and on remote systems.

Marine technologies are likely to be reasonably large-scale in the first instance but will lend themselves to distributed, off-grid applications. Marine energy has potential for application in the Pacific.

Research Issues

Resource Definition and Tools for Assessment

Marine resource information has generally lagged behind its terrestrial counterparts, due in part to the expense and difficulty of taking measurements in such an extensive and demanding domain. Although New Zealand's marine resources and hotspots are known at a coarse level, there is a need for additional measurements to quantify the resource, and the development of validated models and tools to speed the process of resource assessment – i.e., to compile a 'climatology', including extremes. There is also a need to understand and quantify the energy extraction limits to avoid negative environmental impact.

Marine Energy Capture Technology

For wave and, to a lesser extent, tidal stream energy, there are no set paradigms for device type and scale. Hence, although higher risk, this is an area that offers the potential for Intellectual Property generation and commercial investment. The economic considerations for smaller-scale local implementations may be quite different, especially where other (fossil) fuels are being supplemented or replaced. The possibility of using existing structures to complement the design, such as suspended marine farms should also be considered. Related development is required in modelling the device dynamics, including fluid flow models to evaluate performance and downstream fluid characteristics. Extraction device research may also include adaptive technologies to optimise energy capture and provide some control to assist in coping with the source variability. Regardless of the device, there is a need to evaluate performance under New Zealand conditions.

Environmental Factors for Implementation

Any marine energy is likely to be extracted on or near the shore and so the characteristics of the local environment (including the sea floor for mooring, construction, cable laying and ecosystem effects) will need to be well understood and thoroughly monitored. There is little experience on which to build a case for the environmental impact of marine energy deployments. Related research into the consenting issues and public acceptance of installations should be undertaken. From an operational viewpoint, the implementation issues around siting, cable runs, fouling, and issues for retrieval and maintenance need to be understood in order that they can be factored into costing.

Tools for Operations

Since these natural flows are variable, operations and scheduling will be improved through improved forecasting. Research undertaken on modelling for resource definition purposes will be applicable to the development of forecast systems. In practice, a centralised electricity system cannot deal with extreme fluctuations and integration may limit the size and location of sites that can be developed. Scheduling the variable resource will also apply to regional options. Climate variability and change, and its impacts on renewable energy sources, also need to be considered.

An emerging research area considers coupled or linked generation technologies: for example, considering wind (wave) production profiles to evaluate hydro requirements for load-following, producing an understanding of the system impacts of a wide range of variable and distributed inputs, in a central system and regional systems.

It is likely that implementation of marine energy will require local environmental as well as output monitoring, so techniques to achieve this at minimum cost must be developed.

Hydro

Although seen as a mature technology, there is still a need for ongoing development for new applications and to extend the life of existing installations. The main thrust here will be the design and operation of innovative hydro systems that are better integrated into the environment, including flow regimes, water use sharing/allocation and ecosystems. Attention will be directed to smaller schemes, including run of the river and micro systems and their environmental effects. Research that focuses on the development of improved turbines, through improved design is likely to be carried out overseas. Mature areas like this are likely to see research that focuses on the adaptation of overseas designs to New Zealand requirements.

Research areas on the hydro resource include estimating water yields from small catchments, including urban catchments, dams and ponds for preventing run-off, improved models for snow accumulation and melt, water allocation, improved flood estimation for design (including small catchments), flood forecasting and operating rules during flooding, and the impacts of climate variability and change, as well as land use change.

H.3 New Zealand Research

New Zealand-Specific Issues

Marine energy technology development is still limited globally. Countries with active coastal regions near demand, such as the United Kingdom and Portugal, are aggressively developing technologies to harness these resources. New Zealand has similar significant marine resources but development is lagging. There is a need to develop and maintain expertise in these areas.

This is likely to be a significant growth area. The comparison with wind technology and its implementation is often made, with wave energy seen as lagging wind technology by at least 10 years and tidal streams by a further five. New Zealand's current research in this area is relatively limited. The resource issues are solely New Zealand issues, but there are significant opportunities in the development, deployment and operation of marine energy devices where we could seek to develop a fabrication and deployment capability and not just be technology takers.

IP Opportunities
There are IP opportunities in marine energy due to the immature nature of the field. Opportunities exist in the development and modelling of extraction device behaviour and subsequent fabrication. Possible opportunities also exist in the development of tools for the operation of marine devices and their integration into generation networks, related storage options and adaptive operations.

Capability Building
New Zealand has research experience in marine resources, fluid dynamics and the capability to survey and map the sea floor (cable, pipeline surveys) and marine areas. Growth of marine energy extraction will require the capability to guide the deployment and operation of devices in our marine environment. Environmental compliance is likely to be specialised and so a research understanding that facilitates both energy generation and community acceptance is required.

If we are to generate IP and manufacture specific devices, then we need to increase our involvement in development, either on our own or through overseas links. This calls for good alignment of the appropriate researchers with energy and engineering industries within New Zealand.

Watching Brief
Marine energy extraction devices underpin all future development and so a close watching brief should be kept on these developments, especially the most mature technologies. Note that the relatively small Portuguese economy is leading the way in terms of wave energy implementation, so it is not beyond New Zealand to take a leading role also.

Other Activities
Much of the work of resource evaluation will use existing monitoring equipment and data sets that have been generated for other marine research. In most instances, this would need to be complemented with specific measurements at sites with energy potential. The same applies to atmospheric and hydrodynamic models (wind, waves and tides) that can be developed for resource assessment. These same models also form the core elements to be incorporated into any forecasting tools, for both marine and hydro operations and for research on integration of multiple energy sources. This related research is carried out in other research portfolios, but the application to energy research must be emphasised.

There has as yet been no test of the public acceptance of marine energy devices. Although a similar deployment situation prevails for aquaculture, there are differences in terms of the space occupied, the visual aspects and the possible impact on local flora and fauna. The previous lack of coastal planning has led to the establishment of Aquaculture Management Areas, and the future development of marine energy may find itself in a similar situation. A watch should be kept on coastal planning and developments to assess their possible impact on accessibility to marine energy.

H.4 Energy Scenarios

Primary Industry-Led Growth
Marine and hydro energy have a high priority for resource assessment, with technology being imported and adapted to New Zealand conditions. Infrastructure to deliver energy also has a high priority – this would include tools to integrate and forecast the variable sources.

Energy Security
Renewables are maximised in the energy mix, so marine and hydro will have a high priority, with a focus on resource studies and inventory. Applications for isolated communities have a medium priority.

Economic Transformation
Renewables are maximised and so marine and hydro have a high priority with an emphasis on new resources. Optimising the integration is a medium priority.

Energy Conservation
Marine (especially tidal currents) is possibly a niche opportunity - research is needed on the resource, environmental impacts and consents. Research into infrastructure/operations to cater for the variation in energy delivery is also a high priority. Low-head (run of river) hydro is seen as a medium priority.

Table 8 - Summary of priorities for the research activities above

Activity	Growth	Transformation	Security	Conservation
Resource	High	High	High	Medium – possibly niche opportunity
Capture	Medium (transfer & adapt)	High	High	Low
Implementation	Medium – resource assessment	Medium	Medium	Low
Operations	Medium	Medium (source integration)	High	High (predictions to balance the energy mix)
Hydro	High, espcially for smaller catchments	High	High	Medium (run of river)

I. GEOTHERMAL

Facilitator: Ed Mroczek, GNS Science

I.1 Background

New Zealand's installed geothermal power generation capacity is 481 MW_t with 2774 GWh/yr total electricity generated in 2003. This is 7.1% of the national energy supply. Direct use of geothermal heat with an installed capacity of 308.1 MW_t (energy use 7086 TJ/year) is dominated by the paper mill at Kawerau with other uses of direct heat being minor in comparison.

The development of geothermal resources both for generation and direct heat has been stagnant for over a decade, primarily due to the availability of cheap alternative energy sources (gas & hydro), and the perceived negative environmental effects of geothermal combined with the tough regulatory environment. The recent Maui gasfield re-evaluation has confirmed dwindling gas reserves, while several dry winters combined with the increasing costs of imported hydrocarbon fuels has encouraged some New Zealand power companies to begin new geothermal exploration and well drilling. However, these higher energy costs have yet to provide sufficient incentive to overcome barriers to the development of new direct-use applications of geothermal.

Geothermal as an indigenous energy resource has numerous advantages, which include:

- the resources are independent of weather;
- they provide base-load generation 24 hrs a day, 365 days a year;
- as such, the geothermal contribution balances the weather dependency of other renewable energy sources;
- the low gas emissions from geothermal are of growing importance in achieving net reductions of CO_2 under the Kyoto Protocol.

Conservative estimates by MED and the New Zealand Geothermal Association show that geothermal electricity generation could be doubled (i.e., over 1000 MW_e) with presently known resources and technology. To support this expansion sustainably requires research into the efficient utilisation and management of fields as well as mitigating the effects, both technical and environmental, of production.

The theoretical power potential of geothermal in New Zealand is significantly higher than 1000 MW_e. However, exploitation at this higher level will require research into new technologies to enable targeting and drilling deeper resources, increasing permeability in already explored areas of impermeable but hot aquifers and engineering/enhancing artificial aquifers (Enhanced Geothermal Systems or EGS).

Direct-use applications of geothermal for industrial and domestic purposes in New Zealand are significantly underdeveloped. The early application of geothermal steam for the Kawerau pulp mills confirmed New Zealand as a world leader in the late 1950s. However, since then, the ready availability of cheap power has severely constrained further developments. This is an area that offers significant potential savings of grid-based electricity, particularly for the Bay of Plenty region. However, significant research into low-temperature resources, and extensive public education, is needed to raise awareness and utilisation of these resources.

I.2 International Research Activities

Through GNS Science, New Zealand has current active collaborative research relationships and links with many international agencies including: USGS (USA), KIGAM (South Korea), GSJ (Japan), AEA (Switzerland), University of Utah, Energy and Geoscience Institute (USA), University of Alberta (Canada) and Tohoku University (Japan). International research collaboration is also actively pursued with the Coso and Icelandic deep drilling and EGS projects. New Zealand is also an active participant in the Geothermal Implementation Agreement (GIA) through the International Energy Agency (IEA) with the Secretariat located at GNS Science, Taupo. The GIA facilitates the international collaboration in geothermal research and technology.

Significant Areas of International Research

Environmental Impacts of Geothermal Development

Research in this area pursues the identification of possible environmental effects associated with the development of geothermal energy and devises and encourages the adaptation of methods to avoid or minimise their impacts.

Deep Geothermal Resources

It has been recognised that the geothermal resource base can be significantly increased and environmental effects minimised if deep geothermal resources (greater than 3 kilometres deep) could be commercially developed. Complementary research into enhancing or engineering permeability in hot but initially impermeable aquifers is also increasing in importance.

Direct Use of Geothermal Energy

The value and importance of the applications of direct heat use is recognised internationally and considerable research and technology is being undertaken to improve implementation, reduce costs and enhance use.

I.3 New Zealand Research

The above three research topic areas are also of prime importance to the future of geothermal in New Zealand and are actively pursued by New Zealand researchers supported by the Government through the Foundation for Research Science and Technology.

New Zealand-Specific Issues
Much of the international geothermal research is of direct relevance to New Zealand and the reason for our extensive collaborations. However the unique local geological and geochemical setting of our geothermal fields (and the practical reason that wells must be drilled locally) means that the research cannot all be done offshore and must eventually be adapted and applied to New Zealand conditions.

Specific New Zealand issues to be addressed include:

- understanding and mitigation of environmental effects, particularly subsidence and destruction of natural features;
- understanding the connections between fields, and their effects upon each other;
- exploring the potential for industrial, municipal, and domestic sites to make use of power station waste geothermal fluids for direct heat and extraction of minerals;
- resource evaluation for the extensive but under-utilised low-enthalpy resources and better estimates for the capacity already explored in high-enthalpy areas;
- deep research wells (>3 km) and associated technology for permeability enhancement to investigate the commercial development of these deep resources for power generation.

IP Opportunities
Opportunities for developing intellectual property include:

- developing novel technologies for remediation;
- developing technologies and processes to utilise power station waste geothermal fluids for direct heat and extraction of minerals;
- developing techniques and technologies for permeability enhancement to aid commercial development of deep resources (>3km) for power generation.

Capability Building
New Zealand geothermal scientific capability has been severely depleted due to the stagnation of commercial geothermal development in the last two decades, the substantial progressive reduction in research funding and the closing of the Geothermal Institute at Auckland University. At GNS Science, government funding supports five FTE in geothermal research, but about 25 staff has geothermal experience. Of these, only five are younger than 40 years, so there is a need for developing a substantially increased geothermal science capability.

Watching Brief
New Zealand funds (either by government or privately) little geothermal engineering research such as well drilling, high-temperature down-hole tools, power station & electricity generation and direct-use technologies. However, technological advances in these areas can have a high impact for improving the exploration, management and efficient utilisation of our geothermal resources. International collaborations are of prime importance in keeping abreast of new development and GNS Science researchers keep a watching brief in these allied research areas.

Other Activities
The litigious and adversarial process for obtaining resource consents for new or existing geothermal projects under the RMA has been particularly damaging for the public perception of geothermal energy use and development. Public outreach and education is required to redress the balance.

I.4 Energy Scenarios

Primary Industry-Led Growth
In this scenario, there is a large growth in New Zealand's energy demand of 2% to 3% per year. Geothermal energy has the potential to increase very rapidly in the shorter term to contribute 15% of total electricity supply. This could be further increased to >25% with development and exploitation of deep geothermal resources.

Geothermal electricity generation is 10% efficient, but the other 90% of the extracted heat is available for direct-use applications. This expanded power production will therefore make available large quantities of geothermal heat for large-scale industrial direct use in the central North Island. In this scenario, resource evaluation, mitigation of environmental effects and new research into development of deep resources will be required.

Energy Security
In this scenario, security of supply and self-sufficiency is of paramount importance with less emphasis on environmental considerations. Geothermal is indigenous and therefore secure. The weather independence of geothermal ensures secure supply, whereas hydro and wind are weather-dependent. Geothermal balances the weather-dependency of these other renewables. Ignoring environmental and regulatory constraints, one estimate suggests geothermal could supply up to 65% of the present peak demand for electricity (Lawless, NZGA 2002). Research under this scenario requires evaluation of low-enthalpy resources for industrial and domestic use (including ground-sourced heat pumps). Development of deep geothermal resources is now imperative.

Economic Transformation
In this scenario, there is full utilisation of high- and lower-temperature resources for electricity generation and direct heat for industrial and domestic use.

Geothermal has great potential to be used in combination with biomass, specifically in providing low-temperature heat. Research required is still essentially same as in the above scenarios.

Energy Conservation
Under this scenario, where there is a move to energy production from renewables, geothermal research would concentrate on increasing utilisation and energy efficiency both in electricity generation and direct heat as well as on the control or mitigation of negative effects. In electricity generation, geothermal energy is already a low emitter of CO_2 (<100 g/GWh) and for direct use, CO_2 emission may be completely eliminated.

J. HYDROGEN

Facilitators: Rob Whitney and Tony Clemens, CRL Energy

J.1 Background

The main drivers behind the global push towards development of a hydrogen-based energy economy are energy security and environmental considerations. Hydrogen, as an energy vector, could provide a de-carbonised, low-emissions fuel for a transport fleet and for electric power generation at raised levels of efficiency. It is widely accepted that energy conservation measures and the use of biofuels will not be sufficient to achieve the twin aims of energy security and a fully de-carbonised transport fleet if today's usage patterns remain unchanged.

The international community has already mapped out a timeline for the staged introduction of the hydrogen economy. The first application will be as fuel cells in portable devices. This is already happening in 2006. From 2010 onwards, there will be uptake of hydrogen fuel cells in small-scale distributed electricity generation and, from 2015 onwards, in larger-scale distributed generation and large-scale Integrated Gasification Combined Cycle/Fuel Cells (IGCC/FC) with Carbon Capture and Storage (CCS). The big increase comes from 2020 onwards, with the widespread uptake of hydrogen-fuelled vehicles into the transport fleet.

J.2 International Research Activities

Although the impact and benefits of a hydrogen economy may lie as much as 15 years or more in the future, international activity is marked by a sense of urgency. There is wide recognition that a great deal needs to be carried out now in order to make the transition as seamless as possible.

The International Partnership for the Hydrogen Economy (IPHE) was launched in Washington DC in late 2003 in order to encourage hydrogen research collaboration among member nations. The IEA Hydrogen Implementation Agreement is a UK/European-based organisation with similar aims. New Zealand belongs to both.

International research areas and targets are clearly laid out.

Hydrogen Production
Hydrogen, like electricity or petroleum, is an energy carrier that must be produced from energy sources such as biomass, wind, solar, marine, coal or natural gas. Each country must decide for itself the mix of indigenous sources from which it will produce its hydrogen and all production methods require improvements in efficiency and costs.

Hydrogen Storage
This is an intense international research area – especially for improved on-board vehicle storage. Target is 6 to 9% by weight hydrogen – a range of options including chemical hydrides, metal hydrides and carbon nanotubes are being investigated.

Hydrogen Distribution
Most countries within the IPHE and IEA forums have already produced, or have well advanced, 'Roadmaps' identifying the best means of introducing their hydrogen energy infrastructure. All of these Roadmaps show that the time for serious planning and other activities is now.

Hydrogen Utilisation
Major international research effort is into reducing the costs of fuel cell production and operation. Technologies for hydrogen use in ICEs and gas turbines are already well advanced.

Hydrogen – Codes And Practices
These are being developed as part of the international collaboration within both the IPHE and the IEA.

Hydrogen – Public Outreach
Most countries within the IPHE and IEA are developing their own hydrogen energy technology demonstrations and information dissemination strategies.

J.3 New Zealand Research

A hydrogen economy offers New Zealand, as it does the rest of the world, a long-term solution to its energy-related issues - reduced dependence on increasingly expensive oil imports, potentially zero emissions for energy production (electricity and transport) and energy security.

With the urgency and magnitude of major international research efforts aimed at making a hydrogen energy economy happen, New Zealand needs, at the very least, to maintain and develop a level of hydrogen research and consulting expertise, so that if it were to come about, the transition to a hydrogen economy can be accomplished as smoothly as possible and the maximum benefit yielded.

New Zealand-Specific Issues

One key issue for New Zealand is, where will we get our hydrogen from? For the scenarios where this comes from coal, there will be specific questions about coal characterisation and gas clean-up. To a large extent, these will be addressed in the coal research field. A second issue will be affordability – of the new infrastructure required, the raw feedstock, and the energy for conversion.

IP Opportunities

The hydrogen economy will require a revolutionary change in the whole energy production, distribution and usage infrastructure. There will be niche opportunities for New Zealand to develop skills and technologies in hydrogen storage (hydrides, nanotubes), improved and innovative methods for gas clean-up, small-scale hydrogen production and distributed energy systems, where New Zealand already has research expertise.

Capability Building

The following capability building is required:

- New Zealand will need to develop expertise in production from biomass and other renewables;
- New Zealand needs to ensure that it has the research capability to be a rapid adopter of a whole new range of technologies around hydrogen production, gas clean-up, hydrogen infrastructure and gas storage.

Watching Brief

We will need to keep a watching brief on fuel cell developments and other areas where we do not have a research capability.

Other Activities

Other recommended activities include:

- New Zealand will need to develop its own Roadmap for a Hydrogen Economy;
- techno-economic studies will be required, and we will need a to prepare Codes and Practices for hydrogen;
- we will need to be involved in the process of international policy development processes and its dissemination to national policy makers;
- we will need public outreach and technology demonstrations.

J.4 Energy Scenarios

Primary Industry-Led Growth

Under the Primary Industry-Led Growth scenario, where the competitive pricing and affordability of energy is the key issue, the transition to a hydrogen economy may offer a clean and long-term, sustainable energy option in the face of a declining and increasingly expensive and unreliable oil supply. To remain competitive with high energy use, we will need to ensure we have a secure supply of hydrogen from our indigenous energy resources. We will need early development of a good infrastructure.

Energy Security

There will be similar requirement under the Energy Security scenario, where the move is towards security of supply and self-sufficiency. There is likely to be a significant role for coal as a source of synthetic transport fuels. Many of the steps involved in this process are also required in the production of hydrogen, as one of the underlying technologies - gasification - is common to both. Although energy demand will not be so high, we will still need to produce our energy locally.

Economic Transformation

Under the Economic Transformation scenario, the move is away from energy-intensive industries combined with the production of higher-value products. There is a particular emphasis on improving transport infrastructure and many households generate their own energy. The hydrogen economy offers a zero emissions transport fleet and hydrogen fuel cells could provide household energy needs.

Energy Conservation

Under the Energy Conservation scenario, the move is toward renewable-based energy and lifestyle changes. Given the intermittent nature of many of the renewable energy sources, the role of hydrogen as an efficient buffer and as a means of energy storage may find a place. Aspects of the hydrogen research package will be necessary for this role to be performed.

K. CARBON CAPTURE AND STORAGE

Facilitator: Trevor Matheson, Coal Association

K.1 Background

Carbon dioxide capture and storage (CCS) is the separation and capture of carbon dioxide produced by human activities (particularly through the use of fossil fuels) then long-term storage (sequestration) of the CO_2 in geological formations. Internationally, CCS is seen as the only viable fossil fuel emissions mitigation option because it offers the potential to achieve deep reductions in atmospheric greenhouse gas emissions when used in conjunction with other options such as energy efficiency and renewables. The main geological formations that are being considered for CO_2 storage include: depleted oil and gas reservoirs, deep saline aquifers and deep unminable coal seams. Other options include the use of CO_2 to enhance oil and natural gas recovery from non-depleted fields. The capacity of geological storage options has been estimated to be substantially greater than projected total emissions between 2000 and 2050 using a 'business as usual' scenario.

Capture of CO_2 is best carried out at large-point sources of emission, such as power stations, oil refineries, cement manufacture, petrochemical and fertiliser plants, steel works and pulp and paper mills.

Post-combustion capture refers to removal of CO_2 from flue gas streams of conventional (pulverised fuel) power stations, refineries etc. The low concentration of CO_2 in these gas streams means a large volume of gas has to be handled, requiring large and expensive equipment and powerful solvents which reduce overall generation efficiency. CO_2 concentrations in the flue gas streams can be increased greatly by using oxygen instead of air for combustion.

Pre-combustion capture involves reacting the fuel with oxygen and/or steam to give hydrogen and carbon monoxide (synthesis gas). The carbon monoxide (CO) in the synthesis gas can be converted to CO_2 very easily. The CO_2 is then separated and the hydrogen used as fuel in a gas turbine combined cycle plant with minimal CO_2 emissions.

CCS can also be applied to large-scale bio-energy or bio-fuel plants. In this situation, carbon credits could be obtained to offset other emissions or to trade internationally.

Internationally-financed CCS is likely to be important in China, India and other developing countries. Skill sets, software and hardware developed in New Zealand may well have an international market.

K.2 International Research Activities

Capture Technologies

Solvent scrubbing — solvent absorption technology has been used for many years in the oil industry to remove CO_2 from mixtures of gases and commercially is the best established technique. Physical solvents can be used where higher CO_2 concentrations and pressures are available (pre-combustion or oxygen-enhanced post-combustion). A number of alternative capture processes are being investigated.

Research issues are:

- environmental impacts of degraded solvents/new wastes;
- development of more efficient solvents/technologies to reduce costs;
- cryogenic separation for high CO_2 concentrations;
- solid adsorbents/pressure swing adsorption;
- gas separation membranes;
- CO_2 transport and storage.

Geological Storage

For CO_2 storage to be effective, it must be stored for several hundreds or thousands of years. Storage must have low environmental impact, low associated costs, and conform to national and international laws.

Research issues are:

- identification and quantification of potential underground stores;
- safety and security – integrity of overlying cap-rock, regional geology/faulting, groundwater, short- and long-term monitoring;
- risk assessment;
- verification and monitoring – for emissions trading or to meet national commitments;
- environmental and social aspects of new technologies;
- regulatory and legal requirements.

K.3 New Zealand Research

New Zealand has enormous reserves of coal available for energy production. There is also the potential for more natural gas discoveries. A key to making efficient and environmentally benign use of this fossil fuel resource is to minimise the emissions of CO_2 inherent in its use, whether it is in power generation, synthesis gas production, hydrogen production, chemicals, etc. Most of the coal reserves available for mining are in the lower half of the South Island, with little known about potential storage options for CO_2. Taranaki, with its depleted oil/gas wells and established infrastructure, would appear to offer early opportunities for CO_2 storage. These two regions are well suited for the initial focus of CCS research in New Zealand.

In the medium term, we are still likely to import LNG and coal for power generation. Large bio-energy projects could be significant point sources. CCS will be important in both cases.

New Zealand has other large-point sources of CO_2 – oil refinery, natural gas production, cement works, steel mills. These also provide opportunities for capture and storage of CO_2 as a mitigation technology.

New Zealand-Specific Issues

There are specific New Zealand issues that need to be researched:

- define and characterise long-term storage capacity of saline aquifers, depleted oil and gas wells, and deep unminable coal seams.
- risk assessment, including implications of tectonic activity;
- identify current and potential CO_2 emission sources;
- identify relevant technical issues.

IP Opportunities

There are opportunities to develop valuable IP for New Zealand and international markets:

- niche approach to CO_2 capture methods. Currently capture is the most expensive part of the CCS chain. Development of lower-cost technologies (e.g. ceramic membranes) will provide access to a huge international market (large-point sources of CO_2 such as power stations will produce several millions of tonnes of CO2 annually; current capture costs are tens of US$ per tonne);

- application of CCS in tectonically active regions. There are many countries on the Pacific Rim that are investigating CCS. Specialised expertise in this area will be highly marketable internationally (as New Zealand has done with geothermal development).

Capability Building
We need to build a research capability within New Zealand so we can be fast followers or early adopters of new technologies:

- establish distribution/infrastructure requirements;
- develop measurement, monitoring and verification methodology;
- conduct risk assessment, including of the implications of tectonic activity.

Watching Brief
We need to keep a watching brief on international developments.

Other Activities
Things that need to happen which aren't energy research:

- the economics of New Zealand CCS projects;
- public outreach;
- demonstration.

K.4 Energy Scenarios

Primary Industry-Led Growth
In the Primary Industry-Led Growth scenario, there is large growth in energy demand. Coal is very prominent as an affordable energy resource, but carbon emissions are to be reduced. Development of the large lignite deposits in the lower South Island will be a key to satisfying the very high energy demand envisaged under this scenario. Any new gas discoveries would likely result in its increased use for power generation, hence increased carbon dioxide emissions. Viability of CCS is an essential factor in these scenarios.

Energy Security
In the Energy Security scenario, security of supply and self-sufficiency are key goals. There is high reliance on indigenous resources, including coal and gas, and a focus on synthetic fuels/energy conversion technologies. It is possible that New Zealand would reject international climate change treaties, but this would not mean New Zealand would cease to be a 'good global citizen' and ignore environmental considerations: i.e., CCS will play a part in the utilisation of its fossil fuel resources.

Economic Transformation
In the Economic Transformation scenario, although reduced energy dependence is a key goal, local fossil fuels, domestic gas and/or imported LNG will continue to be used for power generation, so CCS will be required. There will also be a high demand for transport fuel that could be manufactured from local coal or gas with the aid of CCS to clean up the production emissions. Alternatives are biomass and imported fuels with emission credits from overseas.

Energy Conservation
In the Energy Conservation scenario, 'clean and green' is the major goal. Biomass is a major energy source in this scenario, and biological or geological sequestration from major biomass projects will be required to offset production and transport emissions and as potential credits for trade or offsets. The reduced energy demand will see energy derived from fossil fuel reduced, but any use of fossil fuels will require the cleanest technologies/zero emissions. CCS will clearly be important if large-point sources of CO_2 remain or are introduced.

L. COAL

Facilitator: Tony Clemens, CRL Energy

L.1 Background

Coal is a major global energy resource and will remain so in the future. It provides 23% of the world's primary energy with 64% of coal utilisation being for electricity production. Long-term forecasts by the IEA and others out to 2050 predict little change overall. Utilisation will increase in developing countries and decline (but remain significant) in developed and Kyoto signatory countries, as they make the transition toward renewable-based energy systems.

L.2 International Research Activities

The challenge is to:

- meet future expanded energy demand;
- solve critical environmental problems;
- address energy safety and security issues;
- reduce the costs of sustainable development.

'Zero' emission coal-based electricity generation plant, in which all wastes (gas, liquid or solid) go to places where their effect may be considered benign, are seen as critical for meeting this challenge. Much of the leading-edge international research is targeted toward making these plants a reality.

Research is carried out in the following areas:

CO_2 Capture And Sequestration
This critical component of any future 'zero' emissions plant is a research area of sufficient scope internationally to warrant separate consideration (see Section K - Carbon Capture and Storage).

Gasification
The core technology of all proposed zero emission demonstration plants, and an area of intense international research activity, is advanced coal gasification. A

particular advantage of these advanced coal gasification technologies is that the initial syngas product may be used not only for electricity production but also for production of other marketable products, including synthetic natural gas, chemicals and synthetic hydrocarbon transport fuels. It may also be used to produce hydrogen – which will itself become a marketable product in a future hydrogen economy, if it happens. All of these are areas of current international research activity – with interest being particularly intense in the electricity generation and hydrogen production areas (see Section J- Hydrogen).

Waste-stream (particulates, ash, tars and condensates) management and utilisation is also an important component of international gasification research.

Combustion
Research is limited to electricity production, with a particular emphasis on improving efficiency and reducing emission levels of NO_x, SO_x and trace metals (mercury is of particular concern).

Combustion in an enriched oxygen atmosphere – oxy-combustion – is also a high-priority research area. The resultant flue gas is high in CO_2, making for ease of separation and capture.

Coal Upgrading
Much of the world's coal supply is either high in ash content and/or high in moisture (lignite). Considerable research effort continues into the development of improved coal upgrading technologies.

Value-Added Products
There is steady, on-going international research into the production of such commodities as carbon filters, molecular sieves and nanotubes from coal.

L.3 New Zealand Research

Though the bulk of New Zealand's electricity comes from hydro power or from burning natural gas, it remains uncertain whether existing and new developments will be able to meet the growing demand. Coal (domestic and imported) presently accounts for only 5% of our electricity production, yet New Zealand has a vast resource. With an energy equivalence in excess of 30 original Maui gas fields, it may offer a long-term solution to meeting future increased electricity requirements; though a large part of the coal resource may not be recoverable, at least several thousand million tonnes could be mined economically using existing technology. A major proportion (75%) of the resource is lignite in Southland or Otago, remote from most areas of major electricity demand (but close to the Bluff aluminium smelter).

A package of research programmes covering many of the high-priority international research areas is therefore of particular relevance in helping New Zealand realise this potential. This package would include:

- matching New Zealand coal properties with advanced coal gasification technology and desired product;
- managing/utilising gasifier waste-streams (solid, liquid, gas);
- matching coal properties to combustion technology;
- managing/utilising combustion waste-streams (solid, liquid, gas);
- identifying the best lignite upgrading technology for New Zealand's needs.

New Zealand Specific Issues
A key issue for New Zealand is to develop an in-depth understanding of the properties of our coal resource vis-à-vis the new, advanced coal conversion technologies. Another key issue is the need to identify the best means for utilising and upgrading our lignite resource.

IP Opportunities
These exist particularly in the areas of developing syn-gas clean-up technologies, both for hydrogen production (see Section J - Hydrogen) and for matching syn-gas production to its intended end-use. The production of value-added products from our coals also offers considerable potential for new IP development.

Capability Building
We need to enhance our expertise in syn-gas clean-up technologies and to enhance our capability in CO_2 capture and storage greatly (see Section K - Carbon Capture and Storage).

Watching Brief
We particularly need to keep up with developments in the area of oxy-combustion and development of techniques for dealing with trace metal (especially mercury) emissions.

Other Activities
Techno-economic studies will be required, as well as a continued, well focused public outreach programme of events and presentations.

L.4 Energy Scenarios

Primary Industry-Led Growth
Under the Primary Industry-Led Growth scenario – high demand, high economic growth – competitively priced, affordable energy is a key issue. As coal is a major affordable energy resource available to New Zealand, it may be expected to play a critical role in meeting the increased energy demand envisaged under this scenario. The development of the Southland lignite fields will play a key role in bringing about the goals of this scenario.

Energy Security
Security of supply and self-sufficiency is paramount and affordability is very important. This scenario is all about

meeting energy needs using indigenous resources, and coal will play a major role in meeting these requirements. Although there may be less emphasis on environmental matters under this scenario than in some others, it still makes good economic sense to use the best technology available in terms of efficiency and environmental performance. The high-efficiency, advanced coal conversion technologies being developed offshore will be required, and we will need to know how to adapt them to our coal resource.

Economic Transformation

Under the Economic Transformation scenario – low demand, high growth – the drive is toward using less energy to produce high-value products. Although energy cost is not a barrier, local fossil fuels will continue to be used and they will be required to be used as cleanly and efficiently as possible. Under this scenario, there will be an increased call for transport fuel. This increased demand could be met by the manufacture of synthetic diesel and hydrocarbons from our coal resource.

Energy Conservation

Under the Energy Conservation scenario – low growth, low demand – the drive is toward renewables-based technologies for energy production. Although the use of fossil fuels is being phased out, it is likely that some coal-fired plant will remain in the mix. Any that does will need to be able to meet strict environmental performance criteria and operate to the standards set by best available international technology.

M. OIL AND GAS

Facilitator: David Darby, GNS Science

This section draws heavily on an analysis of New Zealand Oil and Gas Resources and Prospects, David Darby and Peter King, GNS Science[16].

M.1 Target Outcomes For Petroleum R&D To 2050

Supply of Conventional, Non-Renewable Energy Sources Ensured

The aim here is energy supply from indigenous, conventional, non-renewable fuel resources secured in the short- to medium-term, at internationally competitive prices, to underpin New Zealand's economic growth objectives (notably a return to the top half of the OECD rankings), and to reduce reliance on imported fuels.

Themes

New Zealand’s oil and gas prospectivity is better understood and information transfer is enhanced, resulting in improved international competitiveness and increased exploration’. Requirements:

- **Fundamental knowledge** - Acquisition and analysis of fundamental data on sedimentary depositional systems, subsurface structure, and geological time, to provide the basis for defining new petroleum habitats in New Zealand basins.
- **Fundamental to applied knowledge** - Characterisation of critical petroleum system parameters to predict and highlight exploration viability in under-explored regions (onshore and offshore basins).
- **Applied interpretation tools** - Petroleum system modelling to help quantify and identify undiscovered oil and gas resources.
- **Efficient research data management** - Development of a comprehensive, interactive, nationally significant digital database of petroleum research products and added-value data, to maximise research efficiency and provide seamless delivery of information in alliance with other Government agency stakeholders.
- **Integrated information delivery and visualisation tools** - Development of a series of digital, up-to-date, industry-standard, geo-referenced petroleum systems atlases of individual basins, to provide the next generation reference tools for petroleum exploration, promotion and future research, particularly 4-D modelling of petroleum occurrence.

A Strategic Investment: Increasing Knowledge Levels for Resource Extraction

The MED Energy Outlook to 2025[17] reference scenario predicts that 35PJ per annum of gas from new discoveries will become available after 2010. This is the historical discovery rate, excluding the giant Maui field. Moreover, the Outlook predicts that 60PJ per annum will become available after 2014. There is an inherent supposition that future exploration will be as successful, or more successful, than in the past. The basis for this prediction is unknown although, in reality, we can expect more discoveries as knowledge levels increase, and as we explore in new areas.

In this regard, one fundamental tenet of the petroleum industry is that the biggest discoveries are made in the early part of an exploration cycle within a given area, or related to a particular target concept. However, new ideas, knowledge, and technologies can reinvigorate exploration in established areas (creating new sub-cycles superimposed on the long-term cycle), or can lead to the opening-up of new exploration areas. However, this principle and the known New Zealand oil and gas discoveries must be considered in the correct context. New Zealand has extensive sedimentary basins, particularly offshore, and the only part of our Exclusive

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[17] The Ministry of Economic Development ‘Energy Outlook to 2025’ can be obtained from the following web address: http://www.med.govt.nz/upload/20275/outlook-2003.pdf

Economic Zone considered to be even moderately well explored is onshore and inshore Taranaki. It follows that there is still plenty of upside potential for research and that this research will play a major part in future oil and gas discoveries.

A second fundamental exploration tenet is that relatively little knowledge is needed to broadly assess resource potential over a wide area, but increasing amounts of knowledge (and expenditure) are required to exploit a resource locally (i.e. petroleum production: see Figure 6). Nothing comes cheaply, especially in terms of investigating offshore regions, and the obvious message is that in order to make money ultimately, we need to spend money.

A corollary of this value chain, and another 'rule of thumb', is that data acquisition (for example, seismic surveys) generally costs an order of magnitude less than actual exploration operational activities (e.g., drilling to prove up a commercial accumulation). On the other hand, geo-scientific interpretation generally costs about an order of magnitude less than the original data acquisition. It is this interpretation phase, however, that provides the basis for subsequent high-cost decisions. It therefore makes sense to apply as much care and effort to geo-scientific interpretation as possible.

Figure 6: Modified after Nathan, L. AAPG Explorer, August 2004, p. 26

If it can be demonstrated that New Zealand's extensive sedimentary basins are good prospects for oil and gas, then private companies will spend tens to hundreds of millions of dollars in data acquisition and exploration operations. It follows that for the greatest potential return, Crown investment should be at the lower cost end of the exploration spectrum, rather than on high-risk drilling ventures. The Government has recently 'upped the ante' by embarking on an offshore data acquisition programme, through Crown Minerals. An investor could also stand to achieve more 'bang for its bucks' by contributing to even lower-cost geo-scientific interpretation, through collaborative efforts with FRST research portfolios.

Based on these rules of thumb, it can be surmised that New Zealand exploration will prosper by going into new regions, and by developing new exploration concepts. Both strategies will require, and in turn will contribute to, incremental gains in levels of knowledge. The Government has embarked on this philosophy with the recently-announced gas exploration incentives package.

Impact of R&D and the Size of the Prize: Will Discoveries be Made?

Economic theory suggests that if replacement resources existed, but a supply shortage was looming, market forces (i.e. higher commodity prices) would have resulted in new discovery and development, in time to ensure continuity of supply. The fact that a supply gap has emerged or is imminent - certainly for methanol production and also for thermal electricity generation under 'dry-year' demand - might suggest that the exploration market doubts the capacity for discovery.

However, the simple 'market forces' model is, in this case, flawed. Firstly, early discovery and subsequent exploitation of the giant Maui field swamped the limited New Zealand market and suppressed exploration for two decades. Secondly, as a very small market at the bottom of the south-west Pacific, New Zealand has, for the companies which dominate this global industry, been off the radar screens. Exploration investment has been strengthening over recent years and several discoveries made (for example, the intermediate-sized Pohukura Field, the smaller but useful onshore discovery at Turangi, and the Tui-Amokura-Pateke oil discovery) paint a promising picture for the likelihood of finding other oil and gas accumulations. The main issue is still the need to increase levels of exploration and research investment to bring forth these conceivable additional discoveries.

There are a number of methods for estimating the number and size of petroleum fields left to be discovered in any given region, but all contain inherent factual or statistical uncertainties. To a large extent, economic, market, or geo-political considerations are just as important as geological factors in determining whether wells are drilled and discoveries are made. However, based on known field sizes and geological grounds alone, it is reasonable to expect that a total of many hundreds of millions of barrels of oil and at least 10 trillion cubic feet of gas could be present in New Zealand basins.

This figure excludes any discoveries in the poorly known deepwater, offshore frontier regions.

An estimate of the potential monetary benefit from encouraging exploration is calculated in the following table.

Table 9: Potential Value of a Single Discovery. (from Crown Minerals Commercial Strategy and Structure

Study, Cameron & Company Investment Bankers report, May 1998)

Oil Price (BOE-1) (US$)	Discovery Size MM barrels oil equivalent (MMBOE)	Additional value to Crown of one year acceleration of discovery (in NZ$M)
12	50 (onshore)	4.50
40	50 (onshore)	15.00
75	50 (onshore)	28.12
12	150 (offshore)	13.50
40	150 (offshore)	45.00
75	150 (offshore)	84.37

M.2 Energy Scenarios

Primary Industry-Led Growth

With the emphasis on economic growth, the continuation of a low-cost supply is critical to the success of the Primary Industry-Led Growth scenario. Discoveries of new oil- and gasfields will need to keep pace with the growth in energy usage. The emphasis under this scenario is therefore on finding more sources of fossil fuels and ensuring that the resource life horizon is always sufficiently far in the future to allow price stability, so that long-range business planning can occur.

The research priorities for the Primary Industry-Led Growth scenario are:

- increased exploration for oil and gas with a greatly expanded programme of offshore exploration in, for example, the Canterbury Basin, the Outer Taranaki Basin, the Northland Basin and the Great South Basin;
- developing policies and plans to measure and manage the risks associated with a potential decline in oil and gas reserves if there are no new major discoveries;
- ongoing research to support the efficient conversion of gas to electricity and liquid fuels;
- investigation into resource potential and risks of using methane hydrates.

Energy Security

Under the Energy Security scenario, threats to the continuing supply of oil and gas could come from international turmoil and unstable international oil prices, as well as from pressure placed on the world oil markets by the growing demand from other countries. In order to reduce the impact on New Zealand of these overseas influences, New Zealand will need to develop and manage its own resources of oil and gas. The early emphasis is likely to be on finding how best to manage the existing reserves and on assessing their limits, as these are known energy stocks. Under this scenario, developing what is known rather than gambling on the unknown may be a key driver. A highly conservative view could see a decline in oil and gas exploration in favour of the development of more assured energy sources such as coal and some renewables, but this should be tempered by economic considerations. The capital requirements and operational costs for large-scale coal mining and coal conversion to transport fuels may well be high enough that oil and gas exploration onshore and inshore remains an attractive local option.

The research priorities for the Energy Security scenario are:

- determining the depletion limits of the oil and gas resources that are presently known;
- assessing and publicising the potential for future discoveries of oil and gas in New Zealand's extensive and still poorly explored sedimentary basins, to encourage investment in exploration;
- ongoing research to support the efficient conversion of gas to electricity and liquid fuels;
- capability building for the development of an efficient gas to liquid fuels industry.

Economic Transformation

Under the Economic Transformation scenario, fossil fuels will continue to be used but will be required to be used as cleanly and efficiently as possible to produce and distribute high-value products. This scenario is based on international trade continuing without major disruptions and with no activities that are likely to disrupt oil imports to New Zealand. There is therefore a lesser need to explore for oil, provided that New Zealand can afford to import, but gas exploration would continue, to meet increasing demand for transport fuels and for efficient electricity generation.

The research priorities for the Economic Transformation scenario are:

- continuing exploration for gas with an expanded programme of offshore exploration;
- developing policies and plans to measure and manage the risks associated with a potential decline in oil and gas reserves with no new discoveries;
- ongoing research to support the efficient conversion of gas to electricity and liquid fuels;
- investigation into resource potential and risks of using methane hydrates;
- developing capability for limited LNG use in New Zealand's electricity generation mix.

Energy Conservation

Under this scenario, oil and gas will be present in the energy mix for a time as they are phased out to be replaced by renewable energy-based solutions. As some of the technologies and fuel distribution infrastructure will be appropriate for biofuels, the transition between oil and gas and renewable energy solutions will be reasonably compatible. The oil- and gas-consuming technologies that persist through the phase-out period will be required to conform to the best practice for efficiency and clean operation. The research priority for the Energy Conservation scenario is developing policies and plans to manage the optimal phase-out of oil and gas from the generation and transport fuels mix.

ENERGY FEDERATION OF NEW ZEALAND INCORPORATED (EFNZ)

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The EFNZ is a non-profit, membership-based, professional and independent energy industry association which promotes the sustainable development and use of energy resources in New Zealand and globally. It was established in 1997 by the merger of the Energy Foundation of New Zealand and the New Zealand branch of the World Energy Council. The EFNZ runs an active programme of seminars, conferences, submissions and research projects, both independently and in collaboration with other energy sector organisations.

As a member of the World Energy Council, the EFNZ

- liaises with similar international organisations;
- participates in international research projects on energy issues;
- promotes New Zealand representation at World Energy Council meetings;
- supplies information on the activities of the World Energy Council; and
- participates in World Energy Council study committees.

A range of services is provided to members of the EFNZ including:

- newsletters;
- faxed or emailed circulation of new items;
- seminars, conferences and workshops;
- energy studies;
- distribution of World Energy Council and other energy-related international material;
- collective research commissions;
- participation in international studies and working groups;
- representation of energy industry views; and
- member access to the global energy information system at www.worldenergy.org.

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