MINISTRY OF RESEARCH SCIENCE + TECHNOLOGY
MoRST
TE MANATŪ PŪTAIAO

energy research

ROADMAPS *for* SCIENCE

What is a Roadmap?

This is one of a series of 'Roadmaps for Science', designed to guide New Zealand's science and research activity. Roadmaps are a type of strategy, providing broad context and high level directions on a particular area of science from a New Zealand perspective.

Roadmaps represent the Government's position on the science, noting how our science capabilities should develop to best meet New Zealand's future needs. These are not technological roadmaps, with milestones, targets or detailed research plans. Those details need to be decided by those with the responsibility for funding particular pieces of research, in conjunction with the end-users of research.

These Roadmaps set the context for the detailed work of the Foundation for Research, Science and Technology and the Health Research Council. The Foundation, for example, will work with relevant stakeholders to identify the key research questions at a level of detail below each Roadmap.

By producing these Roadmaps the Ministry of Research, Science and Technology is ensuring that the strategic research investment that makes up a significant part of Vote RS&T goes to those areas that will make the most difference for New Zealand over the long term.

The Roadmaps also set the scene for better co-ordination across government. The directions in each Roadmap not only highlight the areas of science we need to build but also the future skills and connections we need to make.

Ministry of Research, Science and Technology
ISBN : 0-478-06148-X
Publication date : December 2006

ROADMAPS *for* SCIENCE

A GUIDE FOR **NEW ZEALAND SCIENCE ACTIVITY**

Contents

Preface

The provision of reliable, resilient and affordable energy is critical to New Zealand's economic future as well as to our environment and our personal wellbeing. Energy, in its different forms; heats and lights our homes, runs our factories, helps us cultivate and harvest our crops, manage our livestock and process agricultural products. It also fuels the transport that gets us to work and takes our goods to market.

New Zealand is not alone in facing challenges in meeting its energy needs. Internationally, there is a growing understanding of the need to provide energy services in an environmentally sound and sustainable manner. New Zealand's energy future will be guided by key government strategies including the New Zealand Energy Strategy, the revised National Energy Efficiency and Conservation Strategy and by other energy policy initiatives.

Our future energy sources are likely to be more diverse, more distributed and more sustainable. Research is essential if we are to adapt and utilise new technologies for greater energy efficiency and provide new sustainable forms of energy. We also rely on research to understand New Zealand's unique mix of energy resources, our energy infrastructure and the ways we use energy so that we can take full advantage of the opportunities these present.

This Energy Research Roadmap identifies the core research capabilities that will help us meet the energy challenges we face. It also makes it clear these challenges require a co-ordinated approach. We need to improve research co-ordination, enhance our international connections and ensure effective partnerships with industry.

By focusing on these areas, the Energy Roadmap will enhance the important contribution that research makes across a range of energy resources and technologies and promises to play a major role in our drive to meet our future energy needs in a sustainable way.

This Roadmap is one of a series of Roadmaps for Science we will be introducing over the coming months and years. They cover areas of scientific and technological research and development. The Roadmaps for Science represent an important step in providing that guidance. They cover areas of scientific and technological research and development that present significant opportunities for New Zealand, and where we feel more direction will help us make the most of those opportunities.

The Roadmaps for Science will serve us well in ensuring research, science and technology provide a strong platform for an innovative and prosperous New Zealand.

Hon Steve Maharey, Minister of Research, Science and Technology

Summary

Introduction

This Roadmap is one of a series of Roadmaps for Science developed by the Ministry of Research, Science and Technology (MoRST) to guide New Zealand science and research activity.

Its focus is on identifying the core energy research capabilities that New Zealand needs for a sustainable energy future and to give direction on how to effectively maintain and enhance these capabilities.

The New Zealand Energy Strategy, together with the revised National Energy Efficiency and Conservation Strategy and updated climate change policy, will determine the strategic direction for energy policy and are likely to give further guidance to the particular areas of energy research that will need to be progressed to meet New Zealand's energy objectives. These strategies are under development at the time of preparing this Roadmap. While the outcomes of these are unlikely to change the core energy research capabilities identified, the Roadmap may need to be revisited to take into account any new energy directions for the future that are identified.

Context

There is a high level of global interest and investment in energy research and development. New Zealand needs to be in a position to take advantage of developments that result from this worldwide investment. But many aspects of New Zealand's energy resources, infrastructure, needs and efficiency opportunities are unique to this country. There is consequently an important role for New Zealand research in these areas.

New Zealand has followed the international trend of increasing energy research during the oil price rises and shortages in the 1970s and '80s, with reductions as oil prices stabilised in the subsequent decades. More recently interest in energy supplies has increased with the depletion of the Maui gas field, high oil prices, pressures on electricity supplies in dry winters and the need to address environmental effects of using fossil fuels.

The current Government approach to energy policy is influenced by its overall goal of sustainable development, meaning energy use should become more efficient, and renewable energy resources should be fully developed. Secure, resilient and affordable energy services are also core to the Government's economic transformation goal.

Energy Research in New Zealand

This Roadmap focuses primarily on publicly funded research that contributes directly to gaining an understanding or knowledge about New Zealand's energy supply, energy demand and energy infrastructure. It does not address other areas of research that are less directly related to energy outcomes, such as climate science, research on new materials that might contribute to energy devices, urban design and transport initiatives. Broadly the Roadmap covers research that contributes to:

- an understanding of the location, extent and characteristics of New Zealand fossil and renewable energy resources;
- the development and use of technologies, systems and policies that enable the efficient utilisation of energy resources;
- the maintenance and development of New Zealand's energy infrastructure;
- understanding the needs, attitudes and perceptions of energy users toward energy services, and the types of incentives needed to make the transition to a more sustainable energy future; and
- the initiation and development of commercial opportunities in the energy area.

Currently, the Government invests around $18 million in energy research through Vote Research, Science and Technology (RS&T) (including an increase of $3 million in the 2006 Budget). With the exception of research on oil and gas and, to a lesser extent, geothermal and hydrogen, research funding is spread amongst small teams across a range of energy supply and demand research programmes.

Two-thirds of the research funded through Vote RS&T is undertaken by Crown Research Institutes (CRIs) with universities undertaking 19%, and research associations and others accounting for a further 15%.

Research directions

There are three parts to the Government's desired directions for energy research in New Zealand. These reflect the fact that while energy research is essential, the value and contribution of the research is enhanced through a range of research, coordination, linkages and industry partnerships.

The research directions involve:

1. *The building and maintenance of a broad suite of critical energy research capabilities;*
2. *Identification of research capabilities that require a particular focus now; and*
3. *System enhancements to ensure that energy research contributes effectively to a sustainable energy future for New Zealand.*

1 Critical research capabilities

The Roadmap uses a framework of the role and purpose of energy research to help identify critical energy research capabilities that are needed to enable New Zealand to move to a more sustainable energy future, where energy is used more efficiently and energy supplies are likely to be more diverse, renewable and distributed.

The critical energy research capabilities identified are:

- Indigenous energy resource and energy use assessment;
- Bioenergy;
- Carbon capture and storage technologies;
- New energy source and carrier technologies;
- Economic and whole-system modelling;
- Acceleration of uptake and behavioural change for efficiency and energy/growth decoupling; and
- Smart integrated grids for distributed and variable energy sources.

2 Research capabilities requiring a particular focus now

Over time the Government expects research capabilities will be developed, maintained or enhanced in the areas of critical capabilities identified. However, the challenges and opportunities for New Zealand's energy future vary in both their potential importance and the time scale in which they might affect us or provide new energy opportunities. Consequently the Government has identified the research capabilities that require a particular focus now.

The energy capabilities that have been identified for a particular focus now are those that contribute to:

- Increasing renewable resources; geothermal, wind, marine, and bioenergy;
- Reducing energy use and improving efficiency;
- Understanding oil and gas formation processes and geological opportunities for carbon storage; and
- Developing smart integrated electricity grids for distributed and variable energy sources.

3 System enhancements

The purpose of undertaking research in the energy research capability areas identified is to help contribute to New Zealand's strategic energy objectives. This can be most effectively achieved if the research is well coordinated with good international linkages and industry partnerships.

The system enhancements needed to ensure that research contributes effectively are:

- Enhanced coordination in research areas where capability is dispersed across research institutions and across different disciplines and technology options;
- Effective connections developed with overseas research teams and international initiatives, especially in those areas where New Zealand will be adopting or adapting technologies developed internationally; and
- Research capability is strongly linked with industry partners where appropriate, to ensure research is relevant to industry needs and stimulates industry investment in technology development and implementation activities.

These critical research capabilities, and the directions in relation to them, will enhance the contribution of energy research to a sustainable energy future for New Zealand. MoRST will keep progress in these directions under review and will advise Government of the need for any changes. The Ministry will also consider the outcomes of the energy strategy processes that are underway and advise Government of the implications of these on broader energy research programmes.

Directions and capabilities :

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MoRST will keep the directions and actions under review, tracking indicators of progress, and advise the Government on the need to refresh directions by 2011.

1 Introduction

1.1 Why have an Energy Research Roadmap?

There has been a significant increase in the profile of energy issues in New Zealand as factors such as oil price fluctuations, depletion of the Maui gas field, electricity shortages, carbon emission obligations and climate change concerns have affected our society, economy and environment.

Government objectives for energy are addressed in a variety of legislation, strategies and policies by a range of government agencies. Energy research programmes are similarly dispersed and are undertaken by small research groups and individuals across a range of disciplines in universities, CRIs and other research agencies.

The Government has announced the development of a "New Zealand Energy Strategy" (NZES) which is being led by the Ministry of Economic Development. Through this strategy, the Government will review its role in energy policy and direction, and will clarify its vision and steps for future sustainable energy outcomes for New Zealand. Two other related policy areas are also being reviewed; the National Energy Efficiency and Conservation Strategy (NEECS), which is administered by the Energy Efficiency and Conservation Authority (EECA), and a new package of climate change policies which are under development.

This Roadmap does not attempt to pre-empt the strategic direction or outcomes that may be signalled through the NZES or other policies. Instead it focuses on the critical research capabilities that will be required to meet the range of potential energy opportunities and futures that may lie ahead. Once completed, the NZES is likely to give further guidance to the particular areas of energy research that need to progress to meet government energy objectives.

The field of energy research has no greater or lesser importance than other fields of research. It was chosen for a Roadmap because of the identified need to more closely link and coordinate diverse policy objectives with the work of an energy research community that is both multidisciplinary and spread throughout New Zealand.

The critical research capabilities identified in this Roadmap are only a small part of the broad process of energy innovation. This innovation process, or chain, involves the creation of new knowledge and moving of technologies and practices from the laboratory to widespread application in business and the community. It can be a lengthy and costly process. It begins with basic research and development (R&D) and typically follows through applied R&D, demonstration, commercialisation, and diffusion.

The Government has an important role in funding the early research stages of this innovation process, with venture and commercial funding becoming progressively more important along the chain. The core research capabilities, however, are critical to ensuring New Zealand is able to participate effectively in energy innovation opportunities that are needed to bring value to New Zealand.

1.2 Assumptions and focus for the Energy Research Roadmap

We have based this Roadmap on some assumptions about the role and contribution of science in supporting New Zealand's future energy landscape. These include that:

- science should inform government strategic policy and choices about New Zealand's energy future;
- it is not the role of the science system to make those choices or to operate at the level of making such choices (for example, by picking preferred energy pathways);
- changes in investment and systems to support RS&T capabilities can help us meet upcoming energy challenges; and
- this research capability should be relevant and responsive to future needs and priorities.

This Roadmap focuses on the core energy research capabilities or "research building blocks" that New Zealand needs to support the transition to a more sustainable energy future. The Roadmap does not attempt to identify or prioritise the more detailed research that will contribute to any particular energy future that may be chosen.

The NZES and NEECS, in association with decisions on a long-term response to climate change, will provide greater leadership and strategic direction for the future energy landscape of New Zealand. They are also likely to include actions to address barriers in the innovation system which encompasses applied research, demonstration, and commercialisation. Priority areas for international technology collaboration may also be identified.

These documents and policies will give stronger direction to the research community about the mix of specific research programmes that will be needed to achieve the strategic directions and outcomes they propose.

In focussing on critical research capabilities the Energy Research Roadmap identifies important core energy research capabilities New Zealand will need over the long term. These capabilities will support the range of energy resources and technologies that will be required to meet a more diverse, sustainable and distributed energy future. These capabilities are unlikely to be provided by the market because the dominant benefits accrue to the public rather than to private interests.

1.3 This Roadmap

The main audiences for this Roadmap include:

- The Foundation for Research, Science and Technology (FRST), the key agency with primary responsibility for investing in publicly-funded energy research; and
- Research organisations, including universities, CRIs, private research companies, and the organisations that invest in, and supply, the core research capabilities and expertise.

Other audiences include:

- Government agencies with direct responsibilities for energy policy and management, notably Ministry of Economic Development (MED), EECA, and the Electricity Commission;
- Agencies with related roles because of sector-based energy issues, including the Ministry of Transport, Land Transport New Zealand, Ministry for the Environment and Ministry of Agriculture and Forestry;

- Energy consultants who provide some of the critical links between research and its uptake, especially in the commercial sector;
- The commercial sector, including state-owned enterprises such as Solid Energy and Transpower, particularly companies investing in energy infrastructure, energy production, energy system management, resource development and energy research; and
- Research associations with interests in energy supply, energy demand or energy infrastructure.

This Roadmap has been developed by MoRST. It draws on work already done within MoRST and by others in the energy sector, including MED and a major Australian energy road-mapping project that helped in development of Australia's roadmap and analytical frameworks[1]. Several workshop proceedings and scenario development projects captured much of the current debate in New Zealand. Key documents are from:

- The Energy Federation of New Zealand[2];
- New Zealand Business Council for Sustainable Development[3];
- Energy Panel of the Royal Society[4];
- MED Sustainable Energy[5] document; and
- Parliamentary Commissioner for the Environment's report on electricity scenarios[6].

In addition reports have been commissioned by FRST from;

- Dr John Huckerby[7], Power Projects Ltd;
- Professor Ralph Sims and others from Massey University's Centre for Energy Research[8]; and
- Judy Lawrence[9], PS Consulting Limited.

Proceedings from various workshops have been drawn on, including MED's series of workshops on Sustainable Energy[10] in 2005. Information from a range of other research and policy reports (listed in the references at the end of this document)[11], have also been used.

MoRST has held workshops and discussions with many of New Zealand's energy researchers, policy makers and energy consultants to identify New Zealand science capabilities in the area and test the framework used in this Roadmap.

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1 Department of Industry, Tourism and Resources, Australia (2002). "Renewable Energy Technology Roadmap". See http://www.industry.gov.au/retr.

2 Whitney RS and Trolove H (June 2006). "Energy Research Investment Strategy". Produced by CRL Energy Ltd on behalf of the Energy Federation of New Zealand.

3 New Zealand Business Council for Sustainable Development (2005). "A Sustainable Energy Future for New Zealand by 2050". Final report and working papers facilitated by the NZBCSD September 2006. See http://www.nzbcsd.org.nz/energy2050.

4 Energy Panel of the Royal Society (December 2005). "Interim advice to the MoRST Energy Research Roadmap group". Unpublished report. Contact Jez Weston at the Royal Society of New Zealand.

5 Ministry of Economic Development (2004). "Sustainable Energy. Creating a Sustainable Energy System for New Zealand". Discussion paper.

6 Parliamentary Commissioner for the Environment (2005). "Future Currents. Electricity Scenarios for New Zealand 2005-2050".

7 Huckerby J (October 2004). "Future Directions for Energy Research". Report from Power Projects Ltd, commissioned by FRST.

8 Sims REH, Berndt S and Ward M (2005). "Options for Future Energy Research, Development and Demonstration Investment in New Zealand". Project report for FRST, by Massey University Centre for Energy Research.

9 Lawrence J, PS Consulting Ltd (2005). Report to FRST on the business case for sustainable energy research. Unpublished.

10 http://www.med.govt.nz/templates/Page XX 12431.aspx

11 This document also draws on generic ideas and structure from the draft MoRST Nanoscience and Nanotechnologies Roadmap.

New Zealand geothermal power steaming along

Cooling Towers, Ohaaki Geothermal Power Plant

Pohutu Geyser, Whakarewarewa

New Zealand has pioneered much of the world s geothermal research and development activity. The Wairakei Power Plant, commissioned in 1958, was one of the first commercial geothermal electricity developments. It was also the first time that a water-dominated geothermal field had been drilled. Use of steam for direct process heating at the Kawerau wood processing plant begun in 1957; making it the world s largest user of direct geothermal heat. The following decade saw the harnessing of geothermal energy to provide power to the plant.

Overseas aid programmes began in 1973 to assist with geothermal development. The initial geothermal power stations in the Philippines were developed and built by New Zealanders, as was the Kamojang power station in Indonesia. Chile and Ethiopia also benefited from our geothermal expertise. In 1979, the Geothermal Institute was established at Auckland University, providing post-graduate education to hundreds of overseas professionals.

The 1980s saw the commissioning of the Ohaaki geothermal power plant. This early phase of geothermal development between the 1950s and the 1980s saw some 120 wells drilled into 14 geothermal fields, mostly in the Taupo Volcanic Zone. New Zealand was internationally recognised for developing the technology for power production and industrial heat from geothermal resources. Analytical techniques developed then are still in use today. This expertise gave rise to an export of technical services which, at its peak, exceeded $20 million per annum.

The development of comparatively cheap gas fields saw geothermal research reach a hiatus, however, today New Zealand s declining gas fields and the need to supplement our hydro-generation capabilities to provide energy security is again turning the spotlight on our geothermal resources.

Further information on geothermal energy research can be found on the MoRST website: http://www.morst.govt.nz.

2 International context

Section summary

- According to the International Energy Association (IEA), world population growth, combined with sustained economic development, will result in very large additional energy demands in the 21st Century. The IEA considers that the consequent increased use of fossil fuels, including coal, will be environmentally unsustainable.
- A number of renewable energy technologies will help reduce greenhouse gas emissions, but massive increases in carbon capture and storage from coal use are essential if atmospheric levels of CO_2 are to be stabilised at twice the world's pre-industrial level.
- In the Organisation for Economic Cooperation and Development (OECD), nuclear research comprises about 40% of energy research.
- New Zealand needs to be well integrated into international research programmes to be ready to adapt knowledge and technologies for use domestically.
- New Zealand's unique mix of energy resources, infrastructure and energy needs, means that there is a critical role for New Zealand energy research to help us to meet our future energy supply, demand and infrastructure needs.

2.1 Global energy challenges

In June 2006 the OECD held a meeting of Ministers in Paris that addressed R&D priorities to support the energy technologies of the future. A report[12] prepared for this meeting gives a useful summary of energy issues, opportunities and directions from an international perspective. It outlines, on a global basis, the potential energy pathways for the next century and discusses the potential uses of new energy technologies. This section draws heavily on this report.

Some of the international messages are highly relevant for New Zealand and others less so. In addition some of the observations in the report about energy opportunities and technologies are disputed. For example, the OECD report is pessimistic about the role of energy efficiency in reducing global energy demand while other international reports are much more optimistic about the role that energy efficiency can play. The report also fails to discuss some emerging technologies such as marine energy, a potentially large source of energy internationally.

Economic development and rising living standards throughout the 20th Century have been fuelled by an abundant and affordable supply of fossil energy and reliable electricity supplies. Population growth combined with sustained economic development, particularly in countries like China and India, will result in a very large increase in energy demand during the 21st Century. In its "business as usual" scenario, the IEA's 2005 World Energy Outlook sees energy demand growing by 50% between now and 2030. While supplying this level of energy may be achievable in physical terms from fossil sources, the IEA states that it is unsustainable from an environmental perspective, particularly because of the very significant contribution to global warming.

12 Richard Doornbosch and Rt Hon Simon Upton (June 2006). "Do we have the right R&D priorities and programmes to support the energy technologies of the future?" OECD report SG/SD/RT(2006)1.

This magnitude of growth in energy demand will have major implications for the security, affordability and environmental sustainability of energy supplies. In the absence of clear policy actions internationally, the world is likely to retain its dependence on oil and gas, but with a growing movement towards the use of coal. Coal can be used for heat, electricity production and conversion to liquid fuels. Such a growth in fossil fuels brings with it substantial increases in carbon dioxide (CO_2) emissions at levels that would be unsustainable given their contribution to global warming.

The OECD report indicates that if governments want to stabilise atmospheric CO_2 by increasing the share of energy with near zero carbon emissions, then the scale of change required in energy supply is sobering.

To stabilise the atmospheric CO_2 at twice the world's pre-industrial level (~550ppmv) by 2050 would require the supply of an amount of carbon free energy by 2050 that equals the total supply of energy that is currently sourced from all fossil, nuclear and renewable energy sources combined.

There is a wide variety of possible technology solutions that could improve the security and sustainability of the world's energy future. These include technologies that:

- improve energy efficiency;
- improve renewables and nuclear energy;
- allow cleaner use of fossil fuels; and
- change the way that energy is distributed and consumed.

2.2 Energy efficiency

While improving energy efficiency is essential, the OECD report considers that at a world scale it is unlikely to make a substantial contribution to the overall need for new energy supplies. There are several reasons for this. The highest energy demands are from countries that are in an energy intensive phase of economic development and are building the infrastructure to accommodate future growth. Even with efficient use of energy, demand in these areas will grow very significantly. Secondly, while improved energy efficiency leads to lower operating costs, this often leads to further economic development, and associated energy demand, because of the lower cost of energy services. Finally, it is difficult to find substitutes for energy.

An IEA report[13] on energy efficiency programmes is more positive about the value and impacts of energy efficiency programmes. The IEA report considers that energy efficiency measures do, in fact, make a difference to energy use patterns.

The messages from the OECD and IEA reports are that energy efficiency can play an important role in moving towards a sustainable energy future but the OECD report suggests that global energy growth will far outstrip savings from energy conservation measures.

13 Howard Geller, IEA (August 2005). "The Experience with Energy Efficiency Policies and Programmes in IEA Countries – Learning from the critics"

2.3 Renewables

Sunlight is an abundant energy source that can be used directly as heat, or used to produce electricity. Electricity can be produced directly through photovoltaic cells, or indirectly through solar thermal means. Solar technologies are already viable in niche markets such as off-grid use in rural areas. Photovoltaic technology is improving and prices are reducing.

Bio-energy encompasses a diverse range of organic resources from plants, trees, crops, agricultural and municipal and industrial waste. These can be used to provide electricity, heat, and transport fuels. In the poorer nations of Africa, for example, bio-energy is the most important energy source and is used for cooking, heating and lighting. In Brazil large areas of sugar cane are grown to provide liquid transport fuels at a cost that is competitive with oil products.

The widespread use of biofuels for transport fuels is limited by the extensive areas of biomass crops that are needed to produce useful amounts of energy. In many areas the use of land for biomass crops will compete with the need to grow food crops. Other issues related to bio-energy production include environmental sustainability where land has to be intensively managed and fertilised, and low energy conversion efficiencies for starch crops. Producing ethanol from corn, for example, currently only produces about 30% more energy than goes into growing the corn.

A key advantage of bio-energy is that it is the only renewable energy source that can substitute for, or complement, liquid fossil fuels without requiring major modifications to vehicles. Ethanol produced from cellulose from crops or forestry shows promise because of its lower demands for fertiliser and pesticides and because it can be produced from crop residues. However, the technology requires further R&D to become commercial.

There is considerable potential to expand wind generated electricity through the use of existing turbine technology. However, the variability of wind presents challenges to transmission, storage and load management in electricity grids.

Geothermal energy is currently limited by the geographic availability of geothermal resources. In the future there is likely to be greater use of deep, lower temperature heat using heat exchange technologies. The technology is in its infancy but could potentially be used over much wider geographic regions.

Hydro-electricity generation is a mature technology and is currently the world's largest renewable resource for electricity generation, producing 2.2% of world total primary energy supply in 2003. Further development is limited by the availability of water resources, and competing land uses for the large areas that become submerged behind the hydro dams.

The OECD report is silent on the potential for electricity generation from marine energy resources. Like solar energy, the energy potential from marine sources is large and varies geographically. Technologies to harness tidal, current and wave energy are in development and early testing stages. The rate at which these technologies are implemented will depend on the outcomes of trials and the costs of the electricity produced.

2.4 Nuclear

A total of 443 nuclear power plants currently produce 6.5% of the world's total primary energy supply. With current nuclear technologies there are between 40 and 100 years of proven uranium supplies available worldwide. New fast breeder nuclear technologies would extend this timeframe by centuries. However, if nuclear energy is to even retain its 6.5% share of production through to 2050, there would need to be some 18 new nuclear power plants commissioned each year to provide for the additional electricity production needed as world energy use increases, and to replace old plants that need to be decommissioned. The current rate of construction is far below this level.

Nuclear fusion could potentially provide a sustainable and abundant energy resource in the future. However, while the concept has been proven, the technical feasibility has not. If R&D is successful, estimates suggest that a demonstration fusion plant may be operational in about 30 years.

2.5 Fossil fuels

Although the current oil prices indicate a shortage of oil supply, the world estimate of conventional and unconventional oil, gas and coal resources indicates that there are enough fossil fuels to meet forecast energy demands for the next century. Technologies are commercially available to convert coal, oil and gas into other liquids, gases and solids. Therefore scarcity in one form can, in time, be met by conversion of other fossil fuels. This means that price rises in oil, for example, can, with the necessary infrastructure, be offset through the conversion of abundant coal supplies to oil.

All fossil fuels are net CO_2 emitters. There are strong environmental drivers to reduce the carbon footprint of these fuels through the capture and storage of CO_2. The technologies to capture, transport and store CO_2 are understood but have not yet been applied commercially to powerstations. It is likely that carbon capture and storage (CCS) will not be ready for widespread use until the 2020s.

2.6 Hydrogen

Internationally, energy is responsible for more than 60% of all greenhouse gas emissions and the transport sector alone for about 21% of greenhouse gas emissions. The transport sector and its associated demand for liquid fuels is likely to grow in future energy scenarios. Therefore the supply of carbon free transport fuels will become increasingly important for environmental reasons in coming decades.

Hydrogen is effectively a zero-emission energy carrier if it is produced from renewable or nuclear energy, or from fossil fuels with CCS. Its advantage is that it can be stored and transported as an energy carrier.

In association with fuel cells, hydrogen provides an opportunity for an efficient and low or zero-carbon energy source for transport and stationary energy sources. The production of hydrogen and applications of fuel cells are technologies which are beginning to be applied in niche stationary applications. The use of fuel cells in cars is currently in a pilot phase and significant R&D efforts are needed to improve performance and reduce cost. Hydrogen storage technologies and hydrogen infrastructure will also need to be developed to allow the wider use of hydrogen as a transport fuel.

2.7 Challenges for renewable and low carbon energy

The OECD report indicates that in theory there is sufficient renewable energy to meet the energy needs of the world through to 2050. This theoretical security of supply, however, assumes that all potential renewable energy resources in all world regions could be fully utilised. In practice, of course, this is not possible, particularly for the very large theoretical potential for solar energy.

For example, a 2005 estimate suggests that 1000 square kilometres of solar cells could gather more than twice the current global energy consumption at an achievable efficiency of 10%. However the total area of photovoltaic (PV) cells in use is a fraction of one percent of this figure. In 2003, PV solar energy provided only 0.039% of the global primary energy supply.

The OECD report indicates that the result of rapidly increasing global energy demand and the inability of renewable or nuclear energy technologies to meet demand through to 2050 means that fossil fuels, in particular coal, are likely to be increasingly important energy resources on a world scale. This means that if atmospheric CO_2 levels are to be stabilised at twice the world's pre-industrial level (~550ppmv) by 2050, there will have to be a massive focus on implementing CCS technologies internationally.

The scale of this is exemplified by an example in the OECD report. A current example of commercial CCS is at the Norwegian natural gas site at Sleipner where 270,000 tonnes of CO_2 is stored annually by reinjecting the excess CO_2 back into the gas field. To capture and store the CO_2 necessary to stabilise the CO_2 in the atmosphere, would require the commissioning of about two Sleipner-sized plants each day for the next 50 years.

2.8 International research and development funding

Publicly funded energy R&D in OECD countries in 2004 totalled about US$9 billion. This figure has declined significantly since the peak levels in the early 1980s. This trend is in contrast to the steady increase in R&D spending overall during this time. Funding for nuclear energy research comprises some 40% of OECD publicly funded R&D. Most of this is on fission, but about 8% is funding fusion research.

The report notes that statistics on energy R&D are difficult to find and interpret. A wide range of research activities can contribute to energy outcomes even though these may not be the focus of the research. Similar difficulties arise with commercially funded R&D data which are often attributed to areas of industry rather than the purpose of the funding.

The OECD report makes several observations about the international mix of publicly funded energy research:

- Despite the enormous scale of potential solar resource, solar receives modest funding;
- Funding for technologies such as wind, geothermal and hydro, is small and matches the limited further research potential of these types of mature technologies;
- While funding for nuclear R&D has been declining in most countries the large share of nuclear research reflects high Japanese and French funding for nuclear energy;
- The declining share of fossil fuel research reflects the maturity of the technology and the commercial incentives for private sector investment;
- While R&D on CO_2 capture and storage has been increasing, it is still very low (~US$100 million pa); and
- R&D is not by itself the solution to mobilising the necessary resources to implement near-zero carbon technologies on the scale required. That will require other policy settings by governments to provide the necessary incentives for change.

2.9 Energy policies of different countries

The summary from the OECD report of the opportunities arising from different energy sources and the associated research funding, provides a useful global picture. In practice this is made up from a broad range of countries with differing energy resources, energy policies and research capabilities. Just as the global picture is different from the situation in New Zealand, other countries have identified particular energy futures that they are working toward. Some research to meet energy objectives will be widely applicable and some will be specific to the particular needs of a country.

Two examples of countries with divergent approaches to energy are Iceland and Australia. Iceland is rich in hydroelectric and geothermal energy but is currently highly reliant on imported oil. The Icelandic government plans to transform Iceland into a hydrogen society by 2030. Research in Iceland is focused on using and transforming the current energy sources to produce hydrogen as a transport fuel. This has attracted attention and funding from car manufacturing and energy infrastructure companies.

By comparison, Australia has large fossil fuel resources, particularly coal, with limited traditional renewable energy resources. A major focus of Australian research is in clean coal technologies that will capture and store the carbon dioxide released by burning fossil fuels. Australia funds a Cooperative Research Centre (CRC) for greenhouse gas technologies (CO_2CRC) with a research focus on the capture and geological storage of CO_2.

2.10 Relevance for New Zealand

The international mix of energy research has both similarities and differences to that of New Zealand. Many of the differences reflect the different energy resources and mixes in New Zealand. For example, geothermal research receives little attention internationally because few countries have significant geothermal resources. On the other hand, very large sums are spent on international research into nuclear energy.

Biofuels is an example that provides opportunities for both stationary energy and liquid transport fuels internationally and in New Zealand. The potential mix of crops and opportunities for biofuels in New Zealand, however, is different from that found overseas. New Zealand does not grow sugar cane and does not have the land available to grow very large areas of corn, soya beans or oil seed crops to produce bioethanol or biodiesel. We do have extensive areas of planted forests and forestry wastes are already used for processing heat and electricity production in the wood processing industry. Forests could also be utilised for liquid biofuels if technologies are developed sufficiently.

The international focus on the need for carbon capture and storage is based in large part on the current and projected increases in the use of coal for electricity generation internationally. New Zealand already has a high level of renewable electricity generation. Decisions on the future use of fossil fuels will influence the need and priority for adopting CCS technologies in New Zealand.

The potential role of energy efficiency and energy conservation in New Zealand compared with other countries is also relevant. As a developed country with high energy intensity, the opportunity for energy savings in New Zealand is much greater than for countries undergoing rapid economic development from a low base.

New Zealand can take two key messages out of the international R&D effort in energy. Firstly, billions of dollars are invested in international energy research programmes. We need to ensure we have effective links with international research so that we know what is going on, and know when and where to engage, so that we can be ready to adopt or adapt new energy technologies for use in New Zealand.

Secondly, New Zealand has a unique mix of energy resources, energy infrastructure, energy needs and energy efficiency opportunities. International research programmes are not going to give us all the answers to our energy questions. There is, consequently, an important role for New Zealand research to help us meet our future needs in the areas of our energy supply, energy demand and energy infrastructure.

3 Relevant New Zealand government policy and strategy

Section summary

- Interest in energy policy was to the fore during hydro development in the 1960s and '70s, the oil shocks of the '70s and the 'Think Big' energy projects in the '80s. Interest waned during the period of low oil prices and commercialisation of the electricity sector in the '90s.
- More recently government and public interest has increased significantly with the need to address climate change obligations, high oil prices, the depletion of the Maui gas field and pressures on electricity supplies in dry winters.
- New Zealand energy policy is guided by a range of energy legislation, regulation and policies, which are themselves implemented by a range of government and state owned agencies.
- The Ministry of Economic Development is leading the development of a New Zealand Energy Strategy. The NZES and the revised National Energy Efficiency and Conservation Strategy will provide improved direction and certainty to New Zealand's future energy objectives.

3.1 The re-emergence of energy as a national policy issue

Energy issues have regained prominence in New Zealand's political, commercial and public arenas after a relatively quiet period during the late 1980s and the 1990s. Changes to the commercial structure of the electricity sector dominated the 1990s but interest in energy policy was not widespread. Prior to that interest was high, with the development of hydro-electricity schemes in the 1960s and '70s, the oil shocks of the 1970s, and 'Think Big' energy projects in the 1980s.

Increasing Government interest in energy is apparent over the last five years, with commitment to the Kyoto Protocol, formation of the Electricity Commission, development of the National Energy Efficiency and Conservation Strategy in 2001 and, most recently, the development of a New Zealand Energy Strategy.

3.2 High level government policies and strategies

Government's high level policies for economic development and transformation[14], sustainable development[15,] and social development[16] influence the choices made about the energy system and its management. These policies provide some context for the Government's overall level of, and approach to, investment in science[17]. The Sustainable Development Programme of Action (2003) is the most specific policy document relating to energy policy development.

14 http://www.gif.med.govt.nz; see Growth and Innovation Framework.

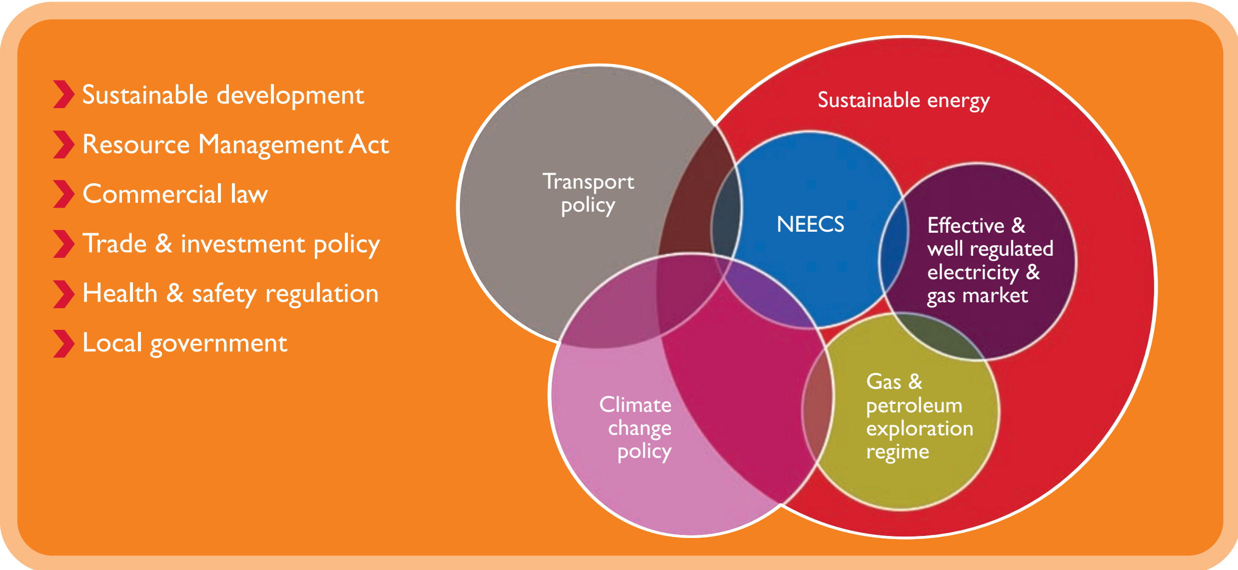
15 http://www.mfe.govt.nz; see Sustainable Development Programme of Action.

16 http://www.msd.govt.nz; see Opportunity for All New Zealanders.

17 See "Science for New Zealand: An Overview of the Science System 2006", http://www.morst.govt.nz.

The diagram below shows the relationships between key government policies that contribute to sustainable energy outcomes. It is based on a figure in the MED's "Sustainable Energy: Creating a sustainable Energy System" (2004). More recently the Government has also identified three key priority areas of action – economic transformation, families young and old, and national identity. These replace the growth and innovation framework priorities. Secure, resilient and affordable energy services are a core requirement of the infrastructure of economic transformation.

Figure 1



There are a range of issue- and sector-specific strategies and policies relating to the energy sector, including:

- the National Energy Efficiency and Conservation Strategy, 2001 (currently under revision);
- New Zealand's international commitments, notably those under the Kyoto Protocol;
- the New Zealand Waste Strategy;
- the New Zealand Transport Strategy;
- Government Policy Statement on Gas Governance, 2004 (Gas GPS); and
- Government Policy Statement on Electricity Governance, 2004 (Electricity GPS).

Generic statutes also influence the energy sector. These include the Commerce Act 1986, Fair Trading Act 1986, Resource Management Act 1991, and the Energy Efficiency and Conservation Act 2000. Sector-specific statutes include the Electricity Act 1992, and the Electricity Industry Reform Act 1998.

Some key areas of national policy are under review and development at the time of developing this Roadmap (discussed below), but the overall goals around a sustainable energy system appear to be well established and reinforced by a number of recent policy statements.

The NEECS was established in 2001 but is currently under review. The goals of this strategy were to:

- Reduce CO_2 emissions;
- Reduce local environmental impacts;
- Improve economic productivity;
- Promote industry development;
- Improve economic resilience; and
- Improve health and welfare.

Two challenging targets were set, but are now considered unlikely to be met:

- Energy efficiency target: an improvement of at least 20% in economy-wide energy efficiency by 2012; and
- Renewable energy target: increase renewable energy supply to provide a further 30 petajoules of consumer energy by 2012.

The transport objectives of the NEECS included:

- Reducing energy use by reducing the need for travel;
- Improving performance of the transport fleet; and
- Increasing the use of low energy transport options.

The New Zealand Waste Strategy emphasises the benefits of waste minimisation on energy and greenhouse gas emission reduction. Reuse of waste reduces energy use and emissions, and landfill gases can be used in place of other fuels. The Strategy does not specifically target energy outcomes.

The New Zealand Transport Strategy also has a wide range of objectives. The objective on environmental sustainability has the closest link with energy.

"Transport will be more energy efficient and environmentally sustainable. Negative local and global environmental effects of transport will be reduced through education, regulation, technology and investment."

New Zealand's climate change policies, including those relating to energy and carbon emissions from energy use, have been reviewed and a new package of policies is being developed[18] at the time of preparing this Roadmap.

New Zealand is a party to the international Framework Convention on Climate Change and in 2002 ratified the Kyoto Protocol that was developed by Convention parties. The Protocol shares the Convention's objective, principles and institutions, but significantly strengthens the Convention by committing so-called "Annex I Parties" to individual, legally binding targets to limit or reduce their greenhouse gas emissions over the period 2008 to 2012. The individual targets for Annex I Parties add up to a total cut in greenhouse gas emissions of at least 5% from 1990 levels during the commitment period 2008 to 2012. New Zealand's target is 0% from 1990 levels.[19] There is no agreed international approach to emission reduction beyond 2012.

The Government's objectives for the energy sector have been summarised by MED as:

Economic objectives:

- Secure and reliable energy supply;
- Efficient economic performance; and
- Efficient and fair pricing, ideally reflecting the full costs of supply.

Social objectives:

- Secure and reliable energy supply (as above); and
- Access to affordable energy by all, such that the least advantaged in the community have access to energy at reasonable prices.

Environmental objective:

- Environmentally responsible energy policy directed at reducing the adverse impacts of energy production, distribution, and use on the local environment, while contributing to international efforts to minimise the rate of climate change.

18 Ministry for the Environment (November 2005). "Review of New Zealand's Climate Change Policies."

19 Ministry for the Environment (2005)

3.3 Key energy challenges for New Zealand

Climate change, energy security, and community interests are key challenges in the energy area.

These challenges are discussed further below.

3.3.1 Climate change imperatives

The 2005 review of climate change policies highlights the concerns about growing transport and energy-related greenhouse gas emissions and implications for New Zealand's climate change commitments.

"A major driver in the growth of carbon dioxide emissions is the growth in transport emissions. These increased, on average, by 3.7% per year. The most important driver of transport emissions has been increased emissions from road transport, with this source accounting for some 89% of the increase in emissions. In terms of fuel source, diesel accounted for some 67.3% of the increase in transport emissions, and petrol some 28.2%. This suggests that increased road freight, together with the growing share of diesel vehicles in the passenger transport fleet, have been important contributing factors."

"Carbon dioxide emissions from energy industries have increased, on average, by 1.8% per year between 1990 and 2003. Emissions from thermal electricity generation increased, on average, by 4% per year. Contributing factors are increased demand for electricity, and the substitution since 2001 of coal for gas in thermal generation because of the sharp decline in the Maui gas field and the 2003 dry-year factor".[20]

3.3.2 Security of energy supplies

A key government objective is the achievement of a secure energy supply. Many factors influence security of supply in New Zealand.

International insecurity over oil supplies in the short to medium term and our dependence on imported transport fuels leave New Zealand in a vulnerable position in terms of supply and cost. New Zealand has little power to influence the supply or the cost of imported fuel. The diverse and dynamic nature of New Zealand's geological history means fossil fuel resources are difficult to measure both in quantity and extent.

Variability in resources is also a fundamental challenge. For example, wind regimes in New Zealand are harsh with large fluctuations over time and space. Climate change is likely to add uncertainty to the supply of renewable resources. For example, wind, rainfall, snowfall and glacial melting patterns may change over time, and the impact of combinations of change is uncertain.

Infrastructural factors that affect security include production capacity, distribution and reliability of plant size, duplication and/or diversity of critical equipment, and flexibility of demand, such as the ability to switch fuel sources and alter demand.

These are a number of factors that affect ability to achieve security of supply, including technology change, regulatory and political uncertainty, depletion of local reserves, growth of demand, changes in demand and location of demand.

The variety of factors affecting energy security highlights the need to understand the character and distribution of New Zealand's indigenous energy resources and how the whole energy system responds to change, and to be clear about whose role it is to develop these understandings.

20 Ministry for the Environment, 2005.

3.3.3 Community and energy stakeholder concerns

Community interest in energy provision and development impacts is high. New Zealand businesses, infrastructure managers, investors and householders place a high value on energy affordability and reliability, and the supply of energy on a day to day basis (rather than medium and long-term security of energy supplies).

New Zealanders also place high value on the environment and this continues to influence the choice of future policy options (most notably the rejection of nuclear energy). The New Zealand Values Study, 2005, noted that most New Zealanders place high value on the environment, giving it priority over economic growth[22]. This finding reinforces the results of the Growth and Innovation Advisory Board report[23] that identified quality of life and the quality of New Zealand's natural environment as core values for New Zealanders.

Some widespread concerns, for example, about threats to environmental and amenity values and impacts on land value, can impact upon energy choices. The desire to protect nationally significant ecosystems, locally-valued environments and landscapes, including protection of "my own backyard" has been obvious in hearings about location and expansion of wind farms, coal-fired power stations, hydro power systems such as Project Aqua, coal mines and transmission lines. Concern about carbon emissions and climate change has begun to gain traction across society.

At workshops held in 2005 by MED to discuss the report "Sustainable Energy: Creating a Sustainable Energy Future", participants stressed the importance of:

- clearer strategic direction from government;
- greater policy certainty for commercial investment decisions;
- guidance from government on balancing competing interests (for example, development versus environment);
- collaboration and integrated approaches to policy (in terms of both energy and how energy interacts with other areas); and
- a mix of approaches, acknowledging that "the market will not provide the best solution to energy issues on its own".[24]

Stakeholder views on energy research investment are discussed further in section 4.

22 Conducted by the Centre for Social and Health Outcomes Research and Evaluation and Te Ropu Whariki. See http://www.shore.ac.nz/projects/Economic%20report%2021.06.05.pdf.

23 Research on Growth & Innovation (2004).

24 Ministry of Economic Development (2005). "Summary of feedback from sustainable energy engagement", pp 3 and 4. Report to the Cabinet Policy Committee. Public document POL/1/35/2. Available at http://www.med.govt.nz.

Rural New Zealand s fuel-cell future

The Proven 2kW wind turbine installed on a hill at Totara Valley. Power generated by the wind turbine will be used to produce hydrogen which will be delivered via a pipeline to a fuel cell at one of the farms.

As an energy carrier suitable for both power supply and transport vehicles, hydrogen is being touted as the clean, green fuel of the future. However, the production of hydrogen requires an energy input, and once delivered, new technologies such as fuel-cells or hydrogen burners are needed to convert it to useable energy.The electrolysis of water is the preferred method of hydrogen production for small-scale distributed production, and especially so if the means of powering the process is renewable.

Energy research engineer Alister Gardiner, from Industrial Research Ltd (IRL) in Christchurch says the technology can be developed to provide affordable, reliable electricity to remote rural communities.The research institute is currently running a pilot project at Totara Valley, a small farming community around 10km from Woodville in the lower North Island.

The project involves installing a small hydrogen production, distribution and utilisation system.This includes a hilltop wind turbine generator and electrolyser to produce hydrogen gas, connected to a fuel-cell and hydrogen burner for water heating at the farmhouse in the valley below.

Because of the relatively long distance and low power it is not economical to run an overhead power line from the wind turbine. Instead a concept dubbed HyLink - a water electrolyser connected to a pipeline, is more feasible.The wind resource is used to power the electrolyser to produce hydrogen gas, which is then piped to the farmhouse.

Because the wind does not always blow reliably, and because rural areas are subjected to power disruptions, converting the available wind energy to hydrogen, which can be held in low-pressure storage in the Hy-Link pipeline, is an ideal solution to providing a more continuous energy supply.The pilot project uses approximately 2km of pipeline which provides approximately 5kWh of hydrogen energy storage.To store more gas, the pipeline diameter can be increased.

Although there are many international research programmes targeting hydrogen and fuel-cell development for the transport sector, Mr Gardiner says there are niche opportunities in the stationary distributed energy sector where New Zealand can lead the market.

When we began looking at small renewable energy technologies, we couldn t source reliable and cost effective electrolyser technology with appropriate specifications.This prompted us to develop a novel electrolyser stack specifically for this type of application.Work is continuing on this, and on the balance of plant and control software at the field site.

This project has research linkages with Massey University and Murdoch University, Perth, Australia.

For further information about the Totata Valley hydrogen fuel cell pilot project see: http://www.irl.cri.nz/scienceandtechnology/ourexpertise/energy-gen-dist/distributed-energy-systems.aspx.

4 The New Zealand research investment landscape

Section summary

- Current annual government investment in energy research is about $18 million annually. This includes an additional $3 million per annum being invested from July 2006.
- Traditional energy supply-side research predominates, but new energy sources and technologies, and research on energy system dynamics, including demand-side management, are components of current investment.
- Except for oil, gas, and to a lesser extent, geothermal and hydrogen research, government-funded energy research capability is spread thinly, with small teams working in discrete areas.
- The extent of collaboration between teams is variable. There are few connections across research topics. International linkages have not been assessed systematically but are known to be strong in some fields.

4.1 What is energy research?

Energy research in New Zealand comprises a broad range of disciplines and topics and is funded by a range of public and private agencies. The research covers the spectrum of basic research to understand underlying energy principles and opportunities, through to operational research to answer immediate questions.

This Roadmap focuses primarily on publicly-funded research that contributes directly to gaining an understanding or knowledge about New Zealand's energy supply, energy demand and energy infrastructure. It covers research that contributes to:

- an understanding of the location, extent and characteristics of New Zealand fossil and renewable energy resources;
- the development, adaptation and use of technologies, systems and policies that enable the efficient utilisation of energy resources;
- the maintenance and development of New Zealand's energy infrastructure;
- understanding the needs, attitudes and perceptions of energy users toward energy services and the types of incentives needed to make the transition to a more sustainable energy future; and
- the initiation and development of commercial opportunities in the energy area.

There are many other areas of research that might contribute to energy outcomes less directly. These include aspects of climate science, research on new materials that might contribute to energy devices, urban design and transport initiatives. These sorts of research are not included in the figures below.

Although the figures below indicate the public and private mix of energy research, the figures and the Roadmap as a whole focus on publicly funded research. Commercial research is both an important and integral part of the energy research mix. It is an area over which government agencies have limited influence and the drivers for the research are generally more operational and shorter term than for publicly funded research.

4.2 Energy research investment in New Zealand

The 2004 Statistics New Zealand R&D Survey[25] provides a broad estimate of the energy research investment in New Zealand (Table 1).

Table 1. Energy research totals from the 2004 R&D Survey

Sector	$ million	% of energy total
Government	16.3	43%
Tertiary Education	5.8	15%
Private	15.8	41%
Total (rounded)	37.8	
New Zealand overall R&D total	1,593.1	Energy research is 2.4% of this total

The types of research undertaken by the investments from the government, tertiary and private sectors are likely to be very different. In particular, much of the private investment by energy sector companies tends to be on short term applied research that is designed to find technical or management solutions to current problems. Research commissioned by government departments is for policy purposes while that invested by FRST and through universities comprises mostly more basic energy research.

Vote RS&T is the source of funding for the majority of New Zealand's publicly funded energy research.

A best estimate for FRST-funded energy investment in 2004/05 is around $15 million. (Note that an additional $3 million was budgeted in the 2006/07 year.) The bulk of this was invested in the Research for Industry Output Class, and to a lesser extent the Environmental Research Output Class, both from Vote RS&T administered by FRST ($14.6 million in total). The remainder ($0.4 million) was in business-related Vote RS&T investments under Technology New Zealand.[26]

Figure 1 shows the diversity of research areas[27]. Table 2 summaries the levels of investment.

25 Statistics New Zealand and Ministry of Research, Science and Technology (September 2005). "Research and Development in New Zealand."

26 This total excludes research on new materials that are designed to contribute to energy devices and new products ($3.96 million that is categorized by FRST as energy research).

27 Research capacity can be estimated from these totals - it costs between $150,000 and $200,000 for one fully-costed FTE (full time equivalent researcher). This equates to five or six fully supported researchers for every million dollars, though very few staff are full time in a single research programme.

Figure 1. FRST-funded investments in energy research 2004/05

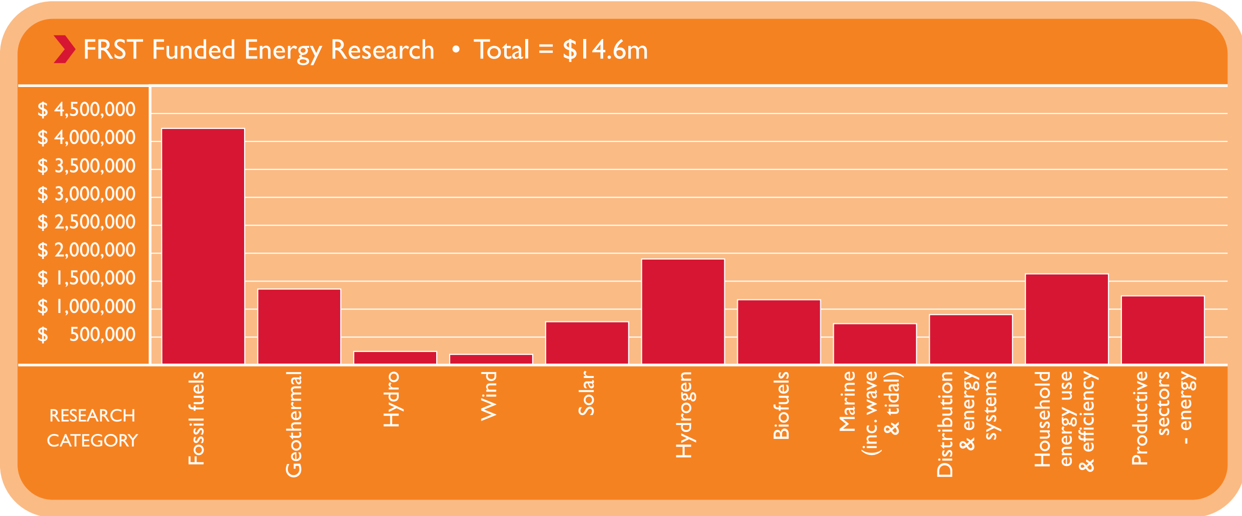


Table 2. FRST, Public Good Science and Technology (PGST) and Technology for Business Growth (TBG) investments on energy research 2004/05

FRST PGST and TBG 2004/05	$	Number of programmes
Fossil fuels	$ 4,280,000	2
Geothermal	$ 1,415,000	2
Hydro	$ 210,000	2
Wind	$ 175,000	2
Solar	$ 810,000	1
Hydrogen	$ 1,909,000	2
Biofuels	$ 1,208,000	5
Marine (including wave and tidal)	$ 727,000	3
Distribution and energy systems	$ 936,000	4
Household energy use and efficiency	$ 1,655,000	parts of 6
Productive sectors – energy use	$ 1,235,000	4
Total	$14,560,000	

Investments in traditional energy sources (covering fossil fuels and geothermal energy) predominate at 41% of the total (Figure 2, below). “New” energy sources (including wind, marine, biomass and new technologies such as hydrogen-powered fuel cells) account for 33%. The biofuels research focuses on efficient burning of biofuel and gasification processes. Much of the hydrogen research involves the production of hydrogen from New Zealand coals. Systems-oriented research is around 26% and covers work on energy distribution, scenario development and optimisation of energy systems. Some of that research, especially that on distributed energy generation, also contributes to increased use of the new energy sources and technologies.

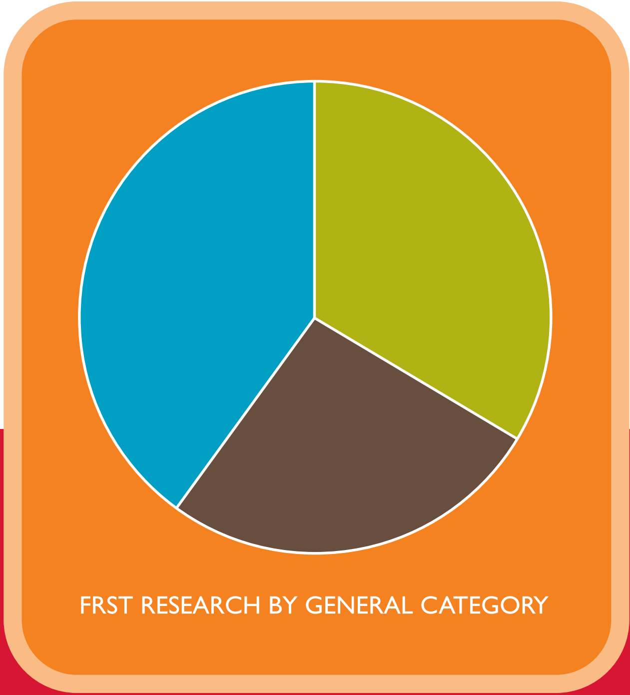


Figure 2. FRST-funded research grouped by general categories

(New sources and technologies, traditional sources, systems research)

KEY

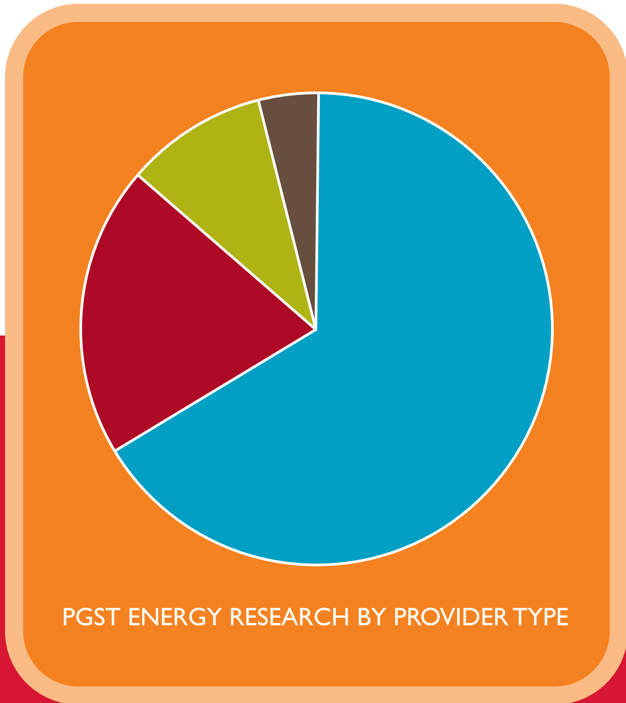
- New 33%
- Systems 26%
- Traditional 41%

Beyond the area of oil and gas research, the FRST-funded capacity is thinly spread across a broad range of research topics (as shown in Figure 1) in a small number of distinct programmes (Table 2). Involvement of CRIs, universities, research associations and others are summarised in Figures 3 and 4.

Figure 3. PGST energy research analysed by provider type

KEY

- CRI 66%
- University 19%
- Research Association 10%
- Other 5%



Crown Research Institutes: Industrial Research Limited (IRL) and GNS Science (GNS) have proportionately high levels of involvement in energy research. GNS's involvement is mainly confined to traditional energy areas, fossil fuels and geothermal energy, whereas IRL's expertise contributes to several new and renewable energy areas. National Institute of Water and Atmospheric Research (NIWA) has particular expertise in working with the Maori community, and in wind, marine, freshwater and climate assessment. In April 2006 NIWA purchased a 50% share in CRL Energy. Scion (formerly Forest Research) has a long-standing involvement in biomass resource and technology development.

Universities are involved in most research areas. Much of their funding is internal, rather than from FRST or external contracts. The 2004 R&D survey indicates tertiary education funding that supports energy research is $5.8 million (including Vote Education Equivalent Fulltime Students (EFTS) and Performance Based Research Fund funding). There are no Centres of Research Excellence (COREs) in the energy research field.

Massey, Auckland and Canterbury universities, and to a limited extent UNITEC, are involved in the engineering/technical aspects of energy supply as well as systems research (scenario and network optimisation/ management research). Otago, Waikato, and to a lesser extent Massey universities, are heavily involved in demand-side management, especially energy efficiency and reduction, including implementation of new technologies and industrial processes for this. Victoria, Canterbury and Auckland universities have expertise in sustainable buildings and energy efficient elements of construction (along with the non-university research group BRANZ).

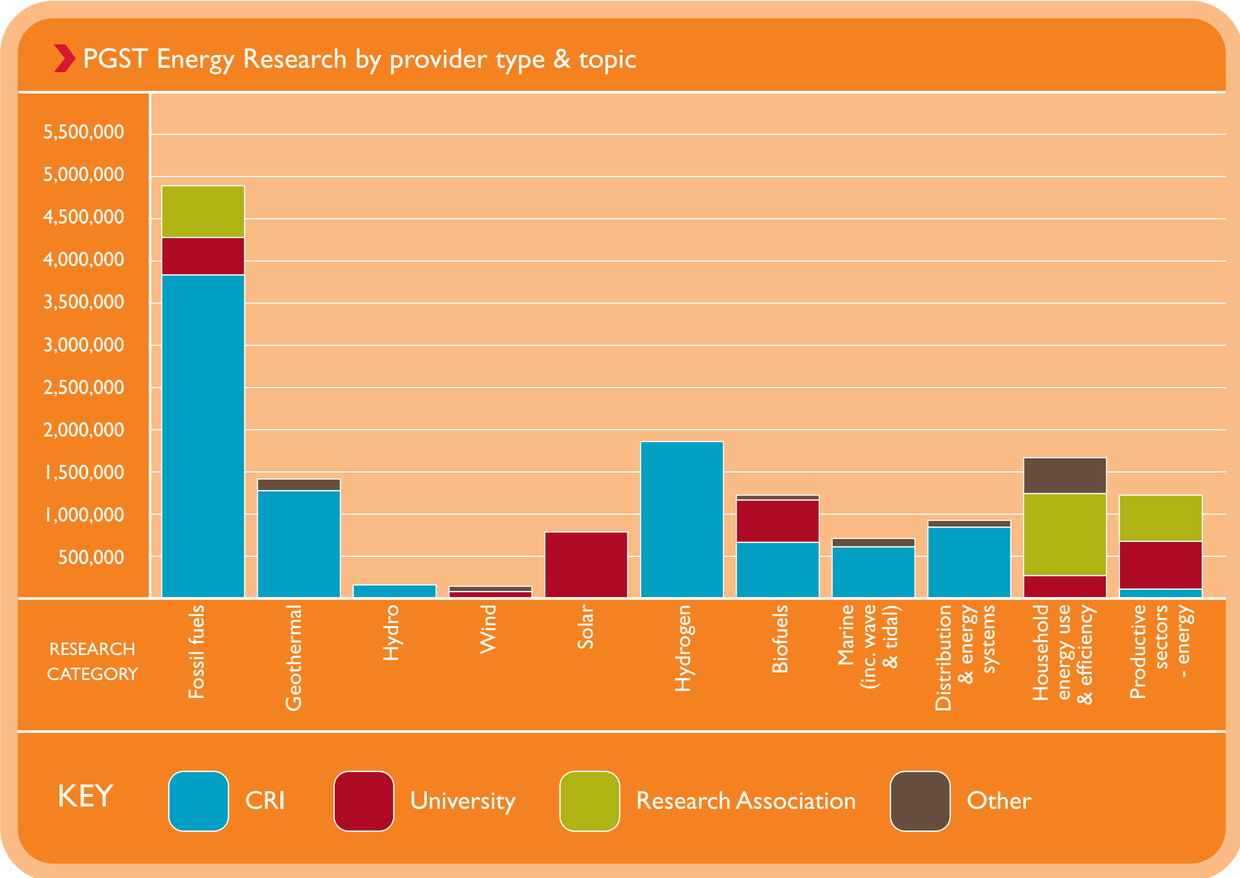
Otago University has initiated the establishment of a National Energy Research Initiative (NERI), which aims to improve collaboration in research on energy issues across disciplines and institutions. This involves most universities and CRIs.

Research Associations, or groups that have evolved from them or from government structures, such as BRANZ, OPUS Central Laboratories and CRL Energy, have some FRST-funded involvement in specific areas of expertise: BRANZ and the Beacon Pathways consortium address energy as a factor in building use and construction. OPUS is involved in transport system research. CRL Energy has expanded beyond coal research into other gas systems (notably hydrogen and carbon capture and storage). Canesis (formerly Wool Research Organisation of New Zealand) leads research into primary sector sustainability, and includes assessment of energy use in production.

Private companies Transport Engineering Research New Zealand Limited (TERNZ) and Pinnacle Research join OPUS and the University of Canterbury as major players in transport research (but not all are funded under Vote RS&T in 2005/06). All have some capability in transport energy efficiency and systems analysis. MTP Solutions is a recent spin-off company from IRL. It has experience in materials performance technologies related to strength, wear and corrosion properties of metals used in energy industries.

Subcontracts and related input from consulting/ research firms in other topic areas has not been estimated, but several are taking a lead in certain fields, especially technology development. Examples include Agrigenesis in biofuels, Waste Solutions Ltd in biomass conversion, Power Projects Limited in marine energy, and Thermocell in solar heating.

Figure 4. PGST energy research providers in each topic area



Collaboration and industry linkages. Several topic areas are characterised by durable collaborations between research providers (for example IRL and CRL Energy in hydrogen research, Massey University and Scion in biomass, and GNS and the University of Waikato in oil and gas). Teams in other areas seem to be relatively independent.

The need for stronger links and the extent of international collaboration has not been assessed, but stakeholders have expressed views on these matters (see below).

4.3 International connections and partnerships

New Zealand researchers are involved in a range of international research collaborations and partnerships. While many of these focus on particular research programmes, others have a more formal basis. For example, New Zealand institutions are members of the Australian Cooperative Research Centre for Greenhouse Gas Technologies (CO2CRC), and New Zealand is a member of the International Partnership for the Hydrogen Economy (IPHE[28]).

The IPHE is committed to accelerating the development of hydrogen and fuel cell technologies to improve energy security, environmental security and economic security. Being a signatory to the IPHE commits New Zealand to supporting an active hydrogen research programme and to develop and promote a hydrogen roadmap for technology implementation in New Zealand. This partnership:

- provides a forum to profile New Zealand developed technologies of niche or global impact;
- gives New Zealand researchers fast-track access to state-of-art knowledge and resources; and
- enables accelerated New Zealand uptake of new energy technologies.

28 http://www.iphe.net.

4.4 Stakeholders' views on current energy research investment and capability

Ministry of Economic Development stakeholder workshops[29] raised a number of concerns about energy research investment, all of which have some relationship to research capability issues. Capability issues were also raised in the more focused MoRST workshop (February 2006) and recent scenario reports. Stakeholders indicated that they:

- want clear directions and more stability (in research and in capability);
- support government taking a more active role in initiatives including demonstrating or piloting new technologies; and
- want an extension of the scope of energy research investment in New Zealand (toward the commercialisation, technology and development end of the spectrum).

Stakeholders also see benefits in:

- increasing capability in some areas;
- making better use of a range of existing expertise and information sources (international, related and retired/previous sources);
- maintaining a broad capability base that is flexible and adaptable; and
- research capability that is strongly connected – with increased coherence across disciplines and among energy research fields, and better connections among agencies, between researchers and users (especially industry users) and internationally.

In their Energy Research Investment Strategy[30] the Energy Federation of New Zealand outlined characteristics of a national research programme which will achieve the energy outcomes they desired. The outcomes included efficient and environmentally acceptable use, optimised infrastructure, low and zero emission energy supply, and developing indigenous energy resources in a sustainable manner. They indicated that a national research programme should:

1. increase research capability;
2. bring in young talent, and enhance public understanding of energy issues;
3. develop intellectual property;
4. encourage international collaboration;
5. encourage and support industry/government collaboration;
6. be strategically aligned to national goals; and
7. be balanced and considerate of all effects and impacts of the programme on society, the environment and the economy.

29 See MED, 2005, pp 5-6. http://www.med.govt.nz/upload/24300/innovation.pdf.

30 Whitney RS and Trolove H (June 2006). "Energy Research Investment Strategy". Produced by CRL Energy Ltd on behalf of the Energy Federation of New Zealand.

4.5 Summary of existing capability

New Zealand's energy research capability is small, thinly spread across energy topics, and, in most areas, lacking coordination of research efforts. This is not to say New Zealand energy research teams are lacking in terms of quality, international standing or willingness to work more collaboratively.

Conventional oil and gas research stands out as a research area with well established, and relatively large, capability, mainly within one organisation. The strength lies in resource assessment capabilities, effective links between two teams (a CRI and a university), and strong links with industry. The industry links help translate new fundamental knowledge into energy development action and policy.

Some previously very strong research areas (hydro, coal and geothermal) are now at a comparatively low level, for various reasons. Other research areas are fragmented geographically, or by topic, or because of the breadth of the research area. Examples of the latter include distributed energy, household energy use including energy efficient building design, and sustainable production systems, where energy research is just one element of a broader research agenda.

The lack of cohesion has several possible explanations. In the bioenergy field several research groups are working on diverse options without a unifying purpose or conceptual structure. Hydrogen, solar, industrial energy use and geothermal energy research fields are covered by relatively few people, with just one or two FRST-funded teams in each area. Areas such as marine energy, wind and hydro have almost no critical mass, a problem that seems unrelated to the maturity of those energy sectors.

Mimicking plants key to solar success

Professor David Officer with porphyrins suspended in solution. On a molecular level, porphyrins resemble plants' chlorophyll, which has been evolutionarily selected for light-gathering efficiency.

While research into the generation of electricity from photovoltaic cells (solar panels) has been carried out for 50 years, the resulting silicon-based technology remains expensive and limited to niche markets. Non-silicon technology such as plastic solar cells holds the promise of future cheap, sustainable sunlight to electricity conversion.

Massey University s Professor David Officer, the founder and director of the Nanomaterials Research Centre, leads an award-winning team of researchers pursuing a range of solar power solutions. Over the last three years, the team has continued to demonstrate the highest efficiency photovoltaic cells used to harvest light in an artificial photosynthesis procedure - imitating the very method that plants use to harvest sunlight, putting New Zealand at the forefront of artificial photosynthesis.

Close to 4,000 times more power than we use falls as sunshine on the earth. What if mankind could capture solar energy with anything like the efficiency that plants manage? What if we could build solar cells with the chemistry available to plants? Clean, green, cheap, world-changingly abundant energy.

Professor Officer has been involved in building molecular structures, porphyrins that resemble plants chlorophyll, which has been evolutionarily selected for light-gathering efficiency. Taking cues from plants, which use many chlorophyll molecules acting together to harvest light energy, they are building arrays of porphyrins. The goal is to get them into just the right orientation to turn light into electricity, and channel the electricity to a less expensive solar cell matrix, such as titanium dioxide. The challenge is to find new ways to assemble the arrays, perhaps even into a new kind of polymer, which would have a myriad of applications from light harvesting to computer chip design.

Polymeric photovoltaics present the tantalizing possibility of producing coatings that function as sunlight-harvesting paints on roofs or even as an integral part of fabrics to produce electricity from sunlight.

Professor Officer s team has been the recipient of both Marsden and Foundation for Research, Science and Technology funding as well as several overseas funds. As part of a FRST-funded Advanced Materials for Energy Technology project, Professor Officer leads the continued development of both titanium dioxide and plastic solar cells as well as a nickel zinc battery development programme.

An Ocean of Opportunity

Potential wave and tidal energy

Harnessing New Zealand s Wave and Tidal Energy

Many coastal countries are now seriously examining the potential of wave and tidal energy, with the first megawatt-scale commercial wave energy installation coming online this year in Portugal. With New Zealand s long coastline and many suitable sites close to major users, the prospects look bright for this type of power generation in the coming decades.

Dr John Huckerby, Director of the energy consultancy, Power Projects Limited, says that wave and tidal energy is where wind energy was twenty years ago. Marine energy generation is not yet cost-competitive with other technologies. But recent presentations by device developers have indicated that this will change rapidly through design optimisation and economies of scale. Indeed their forecasts are that wave and tidal energy devices may eventually be cheaper than wind turbines. Only time will tell.

Industrial Research Ltd, the National Institute of Water & Atmospheric Research, and Power Projects Ltd have formed a consortium to develop wave energy technology suitable for New Zealand s environment. The New Zealand Wave Energy Technology Research and Development Programme (WET-NZ) has identified several potential sites for wave energy converters and researchers are carrying out wave-structure hydrodynamic modelling and wave energy analysis.

New Zealand is ideally placed for exploiting wave energy potential. Typical wave energy levels off the west coast of Northland are 10kW/m of wave crest in the summer and 25kW/m of wave crest in the winter. This trend matches the New Zealand seasonal electricity demand and could provide insurance against hydro dry years. We estimate that the untapped near-shore energy resource represents over 40 times the current New Zealand electricity consumption, although not all of this energy will be extractible.

Another part of the WET-NZ project has involved examining the potential of ten different wave energy devices from four different countries and New Zealand researchers from IRL designing a new device based on a novel direct-drive concept with a much smaller environmental footprint than existing devices. A key difference with this device is that it will actively respond to the site wave characteristics (like a variable speed wind turbine), resulting in an improved capacity factor. The device will be moored so that it is largely sub-surface in transitional/deepwater waves (20-100m). It will seek to harness both kinetic and potential energy from passing waves. The project aims to deliver a marine-tested prototype wave energy converter by July 2008.

For further information about New Zealand s Wave Energy Technology research programme visit: http://www.wavenergy.co.nz.

5 Directions for energy capability

5.1 Summary of New Zealand's energy challenges

The international and national context (previous sections) highlight the major energy-related challenges to be faced in future at the global level. Several organisations in New Zealand have used scenario-development as a way to look at the challenges New Zealand might face and how the country might respond to those challenges. The scenarios are not predictions – they are tools for encouraging future thinking, and a broad perspective on up-coming issues. An Energy Federation report and workshops (2006) drew these scenario projects together.

New Zealand will have to make some choices and respond to several established pressures, most notably, the development of an energy system with a low carbon emission footprint. There is a strong common thread among the research directions, irrespective of the scenarios, choices and possible energy futures. Emphasis, urgency and balance of effort might change but the research directions are surprisingly consistent.

The common themes in the scenarios are the need to:

- Ensure *security of supply* by:
  - Developing a comprehensive knowledge of New Zealand's energy resources;
  - Developing new technologies which deliver energy from sustainable resources; and
  - Improving our energy delivery infrastructure so that new and diverse generation and delivery opportunities can be readily implemented.
- Deliver energy resources and services within acceptable levels of *environmental impact*, including:
  - Developing new technologies which reduce the carbon dioxide emissions from fossil fuels at both centralised generation plants and from the domestic transport sector;
  - An increased use of sustainable energy resources, balanced with their impact on the environment; and
  - Meeting our international obligations relating to greenhouse gas emissions and climate change.
- Stimulate *efficient and effective* use of energy resources by:
  - Undertaking research to support societal changes to promote improved energy use; and
  - Managing public and corporate expectations and responses to the changing energy landscape.

New Zealand needs to respond to the challenges arising from scenarios by:

- Developing local solutions independently where we have New Zealand specific needs or capabilities;
- Building capability to effectively implement international technology in New Zealand; and
- Partnering with international organisations to contribute to energy research of global importance where New Zealand has relevant expertise and will obtain benefit in the long term.

5.2 Introduction to the assessment of future capability needs

The Roadmap uses a framework of the r*ole* and *purpose* of energy research to help identify critical energy research capabilities that are needed to enable New Zealand to make the transition to a more sustainable energy future. These two form a matrix on which energy research can be mapped[31].

The framework has no implications for the priority of the research, or of the quality of research that is required. Excellent research is required for all areas and priorities will depend on the contribution that the research makes to the government's strategic energy objectives.

The role and purpose categories used in the framework are outlined below and set out in greater detail in Annex 1.

The research roles identified in the framework are those of:

- *New Zealand lead* – for research that can only be, or is best, undertaken in New Zealand;
- *Fast adapter* – for research that enables New Zealand to adopt and adapt overseas knowledge and technologies;
- *Emerging opportunities* – for research that links New Zealand with new and emerging energy developments overseas so that their relevance for New Zealand can be evaluated; and
- *Niche/commercial opportunity* – for research where New Zealand has particular expertise or knowledge that may have international, commercial or intellectual property value.

The purposes for the energy research used in the framework are:

- *Understanding resources and issues* – for research that contributes to an understanding of New Zealand's energy resources or energy use;
- *Providing technology solutions* – for research that involves the development of technologies to extract, transform, utilise or manage energy resources and the infrastructure that distributes it and the ways that it is used; and
- *Making it happen/implementation* – for research about energy systems and services that informs national and regional government, commercial users and householders about sustainable energy choices to encourage or enable their adoption.

The two dimensions of the 'role' and the 'purpose' of energy research are one way of looking at the diverse range of research activities that contribute to understanding and meeting New Zealand's future energy needs. As a matrix they help identify energy research opportunities, priorities and gaps.

In this Roadmap the research role and purpose framework is used to map only *critical research capabilities*. It does not attempt to map all of the research being undertaken, or that should be undertaken, in New Zealand. Once the New Zealand Energy Strategy is completed any new energy directions or research directions can be assessed, compared and prioritised using the same framework. It can be used to compare the research that is needed for the future with the research that is being funded now.

31 The research role component is based on an Australian framework, but with an additional category added to reflect areas of world class research in New Zealand with potential commercial opportunity.

5.3 Critical energy research capabilities

Seven areas have been identified as critical research capabilities for New Zealand. These reflect the current state of capability and the challenges we may face in future. Note that this Roadmap focuses on energy research funded by government to support government objectives.

The capabilities identified are therefore those that could be expected to be supported by government science funding. Any additional funding from commercial sources would obviously assist in supporting these capabilities.

The critical energy research capabilities identified in the Roadmap are:

- Indigenous energy resource and energy use assessment;
- Bioenergy;
- Carbon capture and storage technologies;
- New energy source and carrier technologies;
- Economic and whole-system modelling;
- Acceleration of uptake and behavioural change for efficiency and energy/growth decoupling; and
- Smart integrated grids for distributed and variable energy sources.

These capabilities are discussed in more detail below and are followed by a summary table of energy research capability in a matrix using the role and purpose categories discussed earlier.

1	Indigenous energy resource and energy use assessment
The needs	Maintain and in places boost capability to model and understand the dynamics of New Zealand's climate, land, marine and geologically based energy resources, especially interpreting and forecasting variability over time and space, and the constraints this variability poses for resource extraction and use. Develop a comprehensive understanding of the use of energy services in New Zealand.
Purpose	To understand energy resources and energy use issues, particularly to keep future energy options open, and to support viable and environmentally acceptable use of indigenous energy sources.
Role of RS&T	New Zealand lead.
Sectors	Of particular relevance to: • Wind and solar energy resource; • Geothermal resources; • Marine and hydro resources; • Oil, gas, coal and methane hydrates; • Land based bioenergy resources; • Geological CO_2 storage potential; and • Use of energy in New Zealand.

2 Bioenergy	
The needs	Develop comprehensive capability to understand, adapt and possibly lead development of bio-energy resources (including forestry/woody resources) in New Zealand and the technologies needed to utilise them. Retain options and flexibility to move in a number of directions, for example, into niche technology development or New Zealand-specific resource assessment and implementation.
Purpose	To capitalise on the growing international research effort in bioenergy technologies (notably in liquid biofuels) and prepare for either fast adaptation to the New Zealand situation or an alternative approach depending on national and international developments.
Role of RS&T	Fast adapter, at present.
Sectors	Of immediate relevance to: • Bioenergy RS&T sector; and • Transport sector.
3 Carbon capture and storage technologies	
The needs	Establish links with international research on CO_2 separation, capture and storage technologies and develop sufficient geophysical expertise to understand the potential for use in New Zealand conditions. (Note that the identification of suitable geological structures for sequestering CO_2 is addressed under 1 above – energy resource assessment).
Purpose	To ensure New Zealand is well positioned to meet low-carbon emission requirements and move into a fast-adapter position if clean fossil fuel technologies are proposed for electricity generation or liquid fuel production.
Role of RS&T	Emerging opportunity.
Sectors	Of immediate relevance to coal resource development and electricity generation including clean coal technologies.
4 New energy sources and carriers	
The needs	Keep a focus on overseas technological developments relating to new energy sources and systems, drawing on New Zealand's biophysical and engineering/technical research expertise.
Purpose	To be able to make informed R&D investment decisions about emerging energy technologies and their application in New Zealand conditions.
Role of RS&T	Emerging opportunities (except marine energy) at present, with scope to move into niche/commercial technologies and/or fast adapter in the future depending on international developments. The first generation of marine energy technologies are in the fast adapter category.
Sectors	Of relevance to: • Hydrogen as an energy carrier; • Fuel cells; • Energy storage systems; and • Marine energy.

5	**Economic and whole-system modelling**
The needs	Build capacity to understand the economic, social and institutional dimensions of the energy system; a capability to enable modelling and prediction of the effects of proposed policies. The capability needs to draw on international modelling experience, but develop New Zealand-specific understanding and expertise.
Purpose	To have the capabilities to support policy and strategic choices about energy options, energy futures and investment choices to enable the implementation of sustainable energy options.
Role of RS&T	New Zealand lead in terms of action relevant to New Zealand policy development. There is also a strong element of fast adapter of international research approaches that are relevant for New Zealand.
Sectors	Of immediate relevance to policy development.
6	**Acceleration of uptake and behavioural change for efficiency and energy/growth decoupling**
The needs	Expertise to understand and stimulate uptake and positive change in overall energy efficiency and energy conservation across sectors. This capability can be applied to both energy supply and demand issues.
Purpose	To speed up and improve implementation and progress towards low carbon energy and energy service options, particularly for efficiency gains and energy/growth decoupling.
Role of RS&T	New Zealand lead.
Sectors	Of immediate relevance to: • Transport (especially for CO_2 reduction); • Households; • Commercial and industrial sectors; and • Primary industries.
7	**Smart integrated grids for distributed and variable energy sources**
The needs	Strengthen technical modelling capability of electricity grid infrastructure.
Purpose	To support the creation and management of a "smart", integrated electricity grid that copes with variable and distributed energy sources.
Role of RS&T	Fast adapter.
Sectors	Of immediate relevance to use of indigenous, distributed resources such as wind, small-scale hydro and in future, marine energy.

Table 3: Critical Energy Research Capabilities - summary based on role and purpose of RS&T

	New Zealand lead	Fast adapter	Emerging opportunities
Understanding the resource and issues	1. **Indigenous energy resource and energy use assessment:** • Wind and solar energy • Geothermal • Marine and hydro • Oil, gas coal and methane hydrates • Land based bio-energy • Geological structures suitable for CO_2 storage • Use of energy in New Zealand		
Providing technology solutions		⇦ 2. **Bio energy** • Liquid transport fuels • Stationary energy fuels ⇦ 4. **New energy source and carrier technologies** • Marine energy technologies 7. **Smart integrated grids for distributed and variable energy sources** (eg wind, small scale hydro, marine energy)	⇦ 3. **Carbon capture and storage technologies** • CO_2 separation, capture and storage technologies ⇦ 4. **New energy source and carrier technologies** • Hydrogen • Fuel cells • Energy storage systems • Coal for hydrogen and liquid fuels
Making it happen / implementation		5. **Economic & whole-system modelling** • for policy development 6. **Acceleration of uptake and behavioural change for efficiency and energy/growth decoupling** • Transport (especially for CO_2 emission reduction) • Household energy • Commercial and industrial sectors • Primary industries	

The arrows indicate that the capability might need to move into a different research role category as the state of knowledge changes or technologies are developed.

Table 3: This table summarises the seven critical energy research capabilities within the framework of the role of RS&T in energy innovation on one axis and the purpose or outcomes on the other. The innovation categories are those described earlier in this section - New Zealand lead, fast adapter and emerging opportunities. The research role of 'niche/commercial opportunity' is not an area which has research that contributes directly to critical research capabilities and in this table this column has been deleted. It does not mean that type of research is not important or valuable for New Zealand. The column would be needed if a wider range of energy research was mapped to the framework. The three broad purpose categories are those of – understanding the resource and issues, the technology solutions needed, and making it happen/or implementation.

There are different ways that energy research can be grouped and the groupings of energy supply, demand and infrastructure are often used. However, the grouping used in the table provides a convenient way of looking at the role of different areas of New Zealand research in achieving outcomes related to resources, technologies and implementation.

There is a wide range of public, private, basic and applied energy research programmes being undertaken in New Zealand. If we were to map all of these research programmes to the table, then most of the cells would have something in them. However, in this Roadmap only the seven critical research capabilities are mapped to it, and these fit in four of the cells.

At present the table is most useful in seeing how and where energy research makes its contribution, rather than whether we are undertaking the "right mix" of research. The "right mix" of research will depend on the government's vision and goals relating to energy in New Zealand. These will become clearer through the New Zealand Energy Strategy, the review of the NEECs and climate change policy.

5.4 Research capabilities requiring particular emphasis

Over time the Government expects research capabilities will be developed, maintained or enhanced in all the areas of critical research capabilities that have been identified. However, the challenges and opportunities for New Zealand's energy future vary in both their potential importance and the time scale in which they might affect us or provide energy opportunities.

An example here is to compare the opportunity and time frames for energy outcomes from research on geothermal and methane hydrate energy sources. Geothermal energy is a proven technology that provides base load electricity production. Research that identifies new geothermal fields or new ways of exploiting different types of geothermal energy could potentially be picked up and utilised quickly.

On the other hand, New Zealand's resources of undersea methane hydrates are potentially very large in global terms. The extent and quantity of the resource can be mapped relatively easily. However, there is currently no technology available to access and utilise undersea methane hydrates. The potential scale of New Zealand's methane hydrate resource means that we need to understand the size of the resource. But the immediate need for this research is tempered by the current lack of technologies to exploit it. If these technologies are developed then the relative need to undertake the research would increase.

The Government's desire for more sustainable energy use, combined with an increasing understanding of environmental impacts of energy use has resulted in the Government identifying a subset of the critical research capabilities that require a particular focus now.

The energy capabilities that have been identified for a particular focus now are those that contribute to:

- Increasing renewable resources; geothermal, wind, marine, and bioenergy;
- Reducing energy use and improving efficiency;
- Understanding oil and gas formation processes and geological opportunities for carbon storage; and
- Developing smart integrated electricity grids for distributed and variable energy sources.

5.5 System enhancements

New Zealand needs to build, maintain or enhance research programmes in the areas of the critical research capabilities identified. However, undertaking this research alone will not ensure it contributes effectively to New Zealand's strategic energy objectives. Achieving this requires a combination of research, coordination, linkages and industry partnerships.

The maintenance of a diverse portfolio of energy research programmes helps ensure research remains relevant in an environment of uncertainty and change, where new technologies, challenges and opportunities will arise over time. New Zealand needs to have research capability to pick up and utilise these new opportunities when they arise. It also provides the sound base and flexibility to quickly shift the focus of research. For example, a shift from fast adapter to New Zealand-lead, or progression from resource assessment to research to "making it happen" as the energy landscape changes and new techologies are developed.

A feature of current New Zealand energy research programmes is their small size and dispersal through different research agencies throughout New Zealand. In addition the research involves a range of disciplines in the physical, biological, engineering, and economic and social sciences. Fragmentation and dispersal of effort threatens to slow progress in areas such as bioenergy. As with many areas of research, the effective linking of ideas, disciplines and expertise is likely to provide the breakthroughs that are able to transform the way we source, use or save energy in New Zealand. The Government therefore wishes to see the coordination of research areas enhanced, particularly where capability is dispersed.

It is important for New Zealand to be in a position to effectively adopt and adapt technologies and knowledge developed in overseas research programmes. Ensuring this requires effective connections with overseas research teams and international initiatives, particularly for the fast adapter and emerging opportunity categories of research.

While research can identify new energy opportunities, industry investment is required to bring most opportunities to the market. Research needs to be strongly linked with industry partners where appropriate, to ensure resource assessment research is relevant to industry needs and stimulates industry investment in technology development, and implementation activities. This is particularly relevant for research relating to indigenous energy resources where New Zealand leads the research.

In summary there are a series of activities that will enhance the contribution of the research to New Zealand's energy objectives. These system enhancements are:

- Enhanced coordination in research areas where capability is dispersed across research institutions and across different disciplines and technology options;
- Effective connections developed with overseas research teams and international initiatives, especially in those areas where New Zealand will be adopting or adapting technologies developed internationally; and
- Research capability is strongly linked with industry partners where appropriate to ensure that research is relevant to industry needs and stimulates industry investment in technology development, and implementation activities.

5.6 Summary of Government directions for critical energy research capabilities

There are three parts to the Government's desired directions for energy research in New Zealand. These reflect the fact that while energy research is essential, the value and contribution of the research is enhanced through a range of research, coordination, linkages and industry partnerships. The research directions involve:

1. The building and maintenance of a broad suite of critical energy research capabilities;
2. Identification of research capabilities that require a particular focus now; and
3. System enhancements to ensure that energy research contributes effectively to a sustainable energy future for New Zealand.

1 Critical research capabilities

The Roadmap uses a framework of the role and purpose of energy research to help identify critical energy research capabilities that are needed to enable New Zealand to move to a more sustainable energy future, where energy is used more efficiently and energy supplies are likely to be more diverse, renewable and distributed.

The critical energy research capabilities identified are:

- Indigenous energy resource and energy use assessment;
- Bioenergy;
- Carbon capture and storage technologies;
- New energy source and carrier technologies;
- Economic and whole-system modelling;
- Acceleration of uptake and behavioural change for efficiency and energy/growth decoupling; and
- Smart integrated grids for distributed and variable energy sources.

4 Research capabilities requiring a particular focus now

Over time the Government expects research capabilities will be developed, maintained or enhanced in the areas of critical capabilities identified. However, the challenges and opportunities for New Zealand's energy future vary in both their potential importance and the time scale in which they might affect us or provide new energy opportunities. Consequently the Government has identified the research capabilities that require a particular focus now.

The energy capabilities that have been identified for a particular focus now are those that contribute to:

- Increasing renewable resources; geothermal, wind, marine, and bioenergy;
- Reducing energy use and improving efficiency;
- Understanding oil and gas formation processes and geological opportunities for carbon storage; and
- Developing smart integrated electricity grids for distributed and variable energy sources.

5 System enhancements

The purpose of undertaking research in the energy research capability areas identified is to help contribute to New Zealand's strategic energy objectives. This can be most effectively achieved if the research is well coordinated with good international linkages and industry partnerships.

The system enhancements needed to ensure that research contributes effectively are:

- Enhanced coordination in research areas where capability is dispersed across research institutions and across different disciplines and technology options;
- Effective connections developed with overseas research teams and international initiatives, especially in those areas where New Zealand will be adopting or adapting technologies developed internationally; and
- Research capability is strongly linked with industry partners where appropriate, to ensure research is relevant to industry needs and stimulates industry investment in technology development and implementation activities.

These critical research capabilities, and the directions in relation to them, will enhance the contribution of energy research to a sustainable energy future for New Zealand. MoRST will keep progress in these directions under review and will advise Government of the need for any changes. The Ministry will also consider the outcomes of the energy strategy processes that are underway and advise Government of the implications of these on broader energy research programmes.

5.7 Ways of building capability

If the research base is to remain broad and flexible enough to cope with changing priorities, energy research capabilities will need to be enhanced. There is potential to boost overall energy research effort (in scale and contribution) by tapping existing capability within the New Zealand science system. These possible sources include university-based energy research groups, and researchers in fields such as information and communication technologies (ICT), new materials and social sciences.

Capabilities could be boosted directly through new investment, encouragement to move into new research areas, or expansion by supporting convergence of research fields. Past capability could be tapped and new expertise could be built up within New Zealand or imported from overseas.

The energy industry also has a growing interest in energy research. While their focus is on the more operational research programmes, the industry recognises the contribution to knowledge and technologies that longer-term research makes. Improved research links with industry partners will provide opportunities for enhancing capability in a number of areas.

6 Putting the Roadmap in place

MoRST will maintain oversight of the Roadmap, advising the Minister of RS&T on the progress of implementation as well as the ongoing relevance of its directions. MoRST expects to consider whether to review and update the Energy Research Roadmap by 2011, possibly earlier. By this time, strategic directions for New Zealand's sustainable energy future will be in place through the New Zealand Energy Strategy and the National Energy Efficiency and Conservation Strategy (and any action plans flowing from these strategies). The timing of the review will depend on the energy outcomes and directions in these strategies.

The Minister of Research, Science and Technology will be directing agencies with responsibility to invest Vote RS&T funds (primarily FRST in the case of energy research) to take account of the relevant directions in the Roadmap in their future investment decisions.

The Minister of Research, Science and Technology will also be encouraging public and private organisations in the wider "energy system" to take account of the directions in the Roadmap and discuss ways to partner with researchers to help move in these directions.

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Annex I

Research role and purpose categories used in the Roadmap

Descriptions of the categories used for the framework for mapping energy research capabilities.

Role of Energy RS&T in New Zealand	
New Zealand lead	This is RS&T that can only be, or is best undertaken, in New Zealand because our energy resources, knowledge or energy uses are unique (that is, no one else will do it), or it provides essential support to important sectors of our economy or society, or is required for our international obligations.
Fast adapter	RS&T that positions and enables New Zealand, in a timely and efficient way, to utilise, adopt or adapt science-related knowledge, products, systems, and technologies that have been developed overseas.
Emerging opportunities	RS&T that ensures that New Zealand is actively involved with new and emerging energy developments and opportunities that arise internationally, so that we are able to evaluate their relevance and priority for their potential use and further development in New Zealand
Niche/Commercial Opportunity	Areas of RS&T where New Zealand has developed particular expertise, experience or knowledge which may have potential international, commercial or intellectual property value, and which may or may not provide solutions for New Zealand's immediate knowledge or energy needs.

The purposes of the energy research	
Understanding resources and issues	Research that contributes to an understanding of New Zealand's energy resources or energy use.
Providing technology solutions	Research that involves the development of technologies to extract, transform, utilise or manage energy resources and the infrastructure that distributes it and the ways that it is used.
Making it happen/implementation	Research about energy systems and services that informs national and regional government, commercial users and householders about sustainable energy choices to encourage or enable their adoption.

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Ministry of Research, Science and Technology ISBN : 0-478-06148-X Publication date : December 2006