ENERGY RESEARCH STRATEGY FOR NEW ZEALAND

THE KEY ISSUES

National Energy Research Institute

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The National Energy Research Institute (NERI) is a Charitable Trust incorporated in New Zealand. Its primary purpose is to enhance New Zealand's sustainability and to benefit the New Zealand community by stimulating, promoting, coordinating and supporting high-quality energy research and education within New Zealand.

Its research members are Victoria University of Wellington, Auckland University of Technology, Scion, and the University of Otago. Its industry association members are the Bioenergy Association, BusinessNZ, Energy Council, and the Energy Management Association of New Zealand.

This publication has been developed in conjunction with the membership and with representatives of energy researchers, sector organisations and government agencies, but does not necessarily represent any of their individual views.

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FOREWORD

Energy is central to our well-being. We use it in all aspects of modern life: to keep us warm, cool, safe and well; to get us around; and to feed us and help us earn a living in the world.

New Zealand has a well-developed energy sector for meeting these basic needs.

The New Zealand Government developed the NZ Energy Strategy 2011–2021 and the NZ Energy Efficiency and Conservation Strategy 2017-2022 to convey its vision for the sector and identify priorities and trends. Other government strategies also touch on energy issues – particularly in transport, the environment, agriculture and food production, business growth, and natural resource use.

Industry and non-governmental organisations have also expressed aspirations for the sector.

Despite differences in the detail, stakeholders generally have similar goals: to see the energy sector realise its potential to support a vibrant economy to the benefit of all New Zealanders, while ensuring developments are environmentally responsible, energy resources are used efficiently, and energy supplies are secure and resilient.

However, the energy sector is facing major changes. These include growing concerns about the impacts of energy-related emissions on the climate; new technologies with the potential to radically change the capture, conversion and use of energy; and changes in consumer expectations and behaviours.

In the main, 'business-as-usual' will suffice, but some changes will be significant and not that easily handled, especially where issues are unique to New Zealand. In these cases we will need to develop ways to manage the risks and realise new opportunities through innovative solutions.

New Zealand needs a coordinated energy research strategy to address these challenges[1].

This Energy Research Strategy has been developed by the National Energy Research Institute in association with over 150 energy stakeholders in research organisations, businesses, industry associations, and Government agencies. It identifies the key issues requiring research, with a particular focus on those that are unique to New Zealand – where imported solutions will not be enough. It presents the significant risks and opportunities for New Zealand that relate to the energy sector; and concludes with research priorities for it.

Its purpose is to provide a strategic framework within which detailed directed research programmes can be developed to address these opportunities and risks.

Janet Stephenson
Chair
National Energy Research Institute

[1] Amongst others the 2017 Energy Policies Review by the International Energy Agency (IEA) has recently recommended that New Zealand move in this direction.

AT A GLANCE

New Zealand's energy sector faces some challenges that are unique and go beyond business-as-usual. These are being driven by environmental concerns, technological changes and changes in consumer behaviours.

The starting point for managing these challenges is to better understand the issues involved – the key opportunities and risks – and what might be done about them. To do this requires medium-term applied energy research.

What follows is a summary of the issues and the framework for the required research.

ENERGY RESOURCES

Overall New Zealand has sufficient raw energy resources to meet its forecast needs, and where there are issues relating to their identification and extraction New Zealand has research investments addressing these.

The outstanding issue is to how to use these resources to best meet future economic, social and environmental needs. Managing the risks from GHG emissions from vehicles that need to travel large distances between refueling (high duty cycle transport) is likely to be the most difficult of these.

ELECTRICITY GENERATION AND DISTRIBUTION

New Zealand has a unique electricity sector that affords us many advantages. It is built on a reliable distribution system and low cost, clean, renewable hydro generation. Its base load generation can be significantly expanded using relatively clean and low cost geothermal, with good quality wind in support.

Electricity system technologies are changing and consumers are taking more control. Most of this will evolve as business-as-usual. However cumulatively these trends will change the way the electricity system operates, and possibly in ways unique to New Zealand. New Zealand needs *to maintain a stable and secure electricity supply in the face of disruptive technologies and consumer behaviours that might disrupt it*.

Hydro, geothermal and wind currently supply around 80% of total electricity demand, but fossil fuel generation will continue to be needed unless new solutions can be found for peak and dry year loads. To help reduce GHG emissions from the electricity sector New Zealand needs *to develop low cost, cleaner ways to reduce peak demand on the grid, and explore cleaner options for dry year support*.

There will be a significant increase in demand for renewable electricity, particularly as the number of Electric Vehicles (EVs) increase. Current wind and geothermal resources can service this load and both have potential for further development. Wind technologies are imported, but the challenge is *to increase the availability of even lower cost, cleaner, geothermal energy for both electrical and thermal loads*.

TRANSPORT

If international transport is included transport represents about half New Zealand's energy use.

EVs are becoming competitive in the low duty cycle vehicle fleet. These are expected to be fully competitive by next decade even with only low GHG emissions charges. Uptake is already occurring under business-as-usual with limited need for significant additional local research. Battery capacity and charging remain issues, and New Zealand has international capability *to help develop charging technologies to assist the introduction of EVs and extend their range*.

Long-haul transport, particularly sea and air, will need liquid fuels for the foreseeable future. As an international trading nation with significant tourism New Zealand is particularly exposed to negative reactions to dirty fuels. While emissions can be reduced by clean replacements e.g. bio-avgas, marine biofuel oil blends, these come at a significant cost. As solutions are developed New Zealand will need to be able to adopt them and have the supply chains to support them. Investment is therefore needed *in assessing the options for high duty cycle transport in New Zealand (both vehicles and fuels) and the implications, along with the future of logistics, and to undertake risk reduction where indicated*.

Transport efficiency has been improving over the years and ICT is now starting to have an impact via transport-as-a-service, trip optimisation, and trip substitution. One area where *New Zealand could take an international leadership role is telepresence, remote sensing and AR/VR*. This should rapidly and cheaply provide more efficient and cleaner alternatives to travel, helping to address distance as a potential future barrier to business in New Zealand.

INDUSTRIAL PROCESSING

Industrial processing is the next biggest user of energy, concentrated in the Wood, Food, Chemicals and Base Metals subsectors. These in turn are dominated by a small number of businesses.

Wood, Pulp, Paper and Publishing subsector is the largest energy user (with the same use as the Residential sector and more than the Commercial sector). 70% is reported to be renewable, with significant contributions from energy derived from the industry's wastes. Expanded biofuels production (e.g. for high duty cycle transport) will also need the fuel to be a relatively low value product alongside a suite of higher value products. This suggests a possible new bio-chemicals industry, analogous to the petrochemicals industry. *Exploration of new products (including biofuels), processes (bio-refineries), supply chains and markets for a potential bio-chemicals industry will be of value*.

The Food subsector is important to the New Zealand economy and has been growing. It is one area where energy consumption has been increased significantly and with increasing exposure to fossil fuels. Adding to this exposure, the production and distribution parts of the Food value chain also produce significant GHG emissions from energy use as well as other sources.

There is a risk for consumer products, like commodity foods, that rely upon significant embedded low cost fossil fuels. Consumer sentiment can turn away from them, reducing margins to current producers, but allowing higher prices for new products that use more expensive but cleaner energy. New Zealand needs *to develop food markets where clean energy earns a premium, and the products and supply chains to service them*.

Encouraging growth in clean products helps manage the risks from fossil fuel use. The Chemicals sector, in particular, transforms fossil fuels into other products, often emitting GHGs at some point in their production and use. If new products could be developed that fixed the carbon we could reduce the risks to the investment in the gas and oil sectors. *Investigation of new low emissions products and processes for the petrochemicals industry* will be of value.

RESIDENTIAL

The concern about the peak demand in the electricity sector goes beyond a desire for stable low priced clean energy. The winter peaks are when New Zealanders who find energy difficult to afford most need it to stay warm and dry. The same families are most vulnerable to other changes that are occurring in energy markets. Many live in rented properties and have limited flexibility to change their energy use. Much has been done, but we need *to develop further low cost ways to keep homes, particularly rentals, warm and dry and assess the impacts of other changes in the energy sector to avoid adverse impacts on the less well off*.

SYSTEM-WIDE ENERGY SECTOR R&D

Because of the likely extent and speed of change in the energy sector, and the uncertainty that surrounds it, we need *to systematically monitor and improve our understanding of the New Zealand energy sector, focusing on risks and opportunities and taking account of its changing environment*.

Finally we need *to continue to invest in New Zealand's internationally competitive energy-related niche R&D capability*. Some niches have already been (indirectly) mentioned: aspects of geothermal, behavioural and markets, AR/VR, inductive power transfer, biofuels, and foods. Others include materials science to improve electrochemical reactions and superconducting power systems equipment.

Photo: John Townsend VUW

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INTRODUCTION

This is the first step in a two-step process to develop an Energy Research Programme for New Zealand. Based on New Zealand's ambitions for the energy sector it identifies the major issues (opportunities and risks) that go beyond business-as-usual and that New Zealand based, medium-term R&D must address.

The second step involves working with stakeholders to develop more detailed research programmes to address the identified issues.

So this first step identifies the issues that should inform our energy research investments.

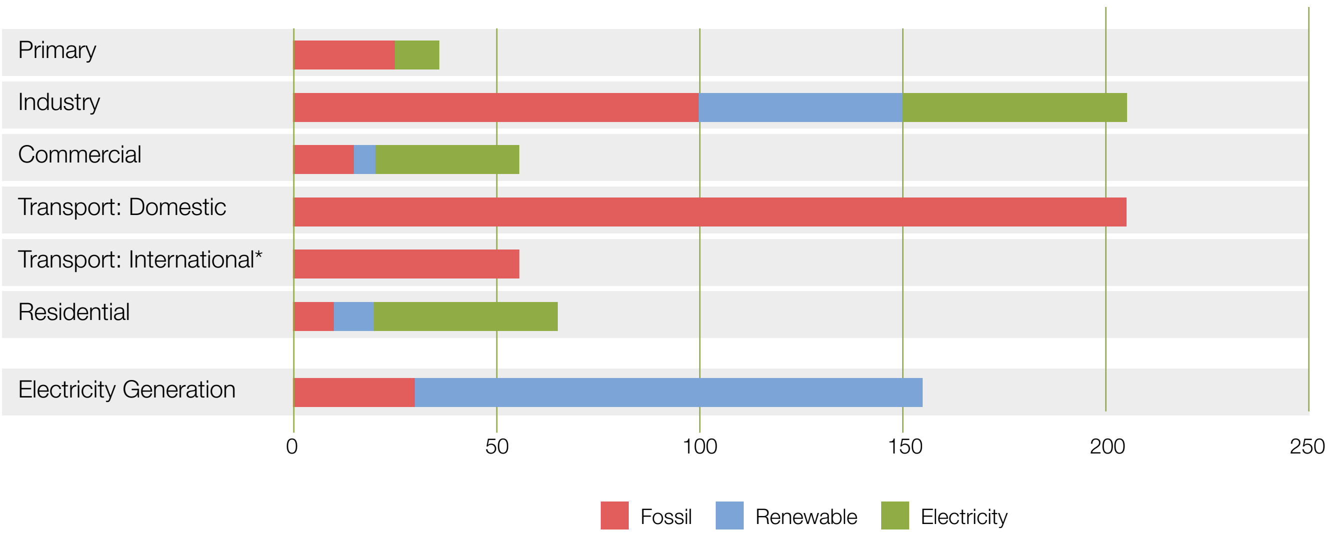
The general themes from the Energy Strategy (NZES) [1] and other documents define the priority issues. New Zealand seeks economic growth and social wellbeing from energy, using supplies that are secure, resilient and meet environmental objectives and obligations, while ensuring everyone's basic energy needs are met.

The Strategy focuses is on the major issues, the areas where the opportunities are large, or the risks are high. This will ensure New Zealand gets the biggest payoff for its research investments.

In some cases, where the area is relatively well understood, the issues for research are well defined. For example, the significance and uniqueness of geothermal to New Zealand is widely recognised [2] [3] and the issues requiring research are tightly defined. On the other hand, the future of vehicles and fuels for the New Zealand heavy transport fleet is not well understood, and reducing that uncertainty is an initial priority for research.

TABLE 1: APPROXIMATE NZ ENERGY END USE BY SECTOR 2015

MBIE Energy Balance Tables, Petajoules



* This is only the fuel sold in New Zealand. The total fuel required to service New Zealand with international transport would be more than double this to account for inward transport fuelling overseas and some large ships not bunkering in New Zealand.

Source: End use from [1]

When it comes to energy New Zealand is a lucky country. It is 80% energy self-sufficient with around 40% of domestic energy derived from renewable sources; rising to 80% for electricity generation [1].

New Zealand has good prospects for increasing renewable electricity generation from geothermal and wind sources. If this can occur at reasonable cost New Zealand can support economic growth, transfer generation from burning fossil fuels, and enhance New Zealand's reputation in international markets through cleaner production.

However, some fossil fuel consumption cannot be easily avoided. Tourism, international trade, and food production all rely heavily on using low cost fossil fuels and economic alternatives are not easily to hand.

A pressing risk is negative market perceptions undermining the value of what New Zealand produces e.g. concerns such as 'food miles' A longer-term risk is New Zealand's ability to meet its commitments in international agreements to reduce greenhouse gases (GHGs) and other emissions. In many cases the extent of these risks and New Zealand's ability to manage them are uncertain so the first step to managing them is to better understand them.

It is opportunities and risks like these that help identify the areas where New Zealand requires medium-term public good energy research.

THE PRIORITY ISSUES:

- Flow from the themes common to the NZES and other energy related strategies;
- Have a significant national impact;
- Are beyond the capacity of individual businesses or sector groups to address ("beyond business-as-usual");
- Require medium-term research investments (5+ years) with impacts well beyond this; and
- Are peculiar to New Zealand and not likely to be solved by overseas research[2].

[2] There will be situations where it makes sense for New Zealand to join an international effort because it is particularly exposed to an issue and/or has particular capability. International transport could be a case in point of the former.

WHAT'S HAPPENING GLOBALLY?

Three global developments are particularly impacting New Zealand's energy sector:

- the international response to the impacts of fossil fuels on the environment;
- changes in global supply and demand for fuels; and
- the availability of new energy technologies.

Other developments with less direct impact (e.g. social and demographic changes) can magnify the effects of these changes.

ENVIRONMENTAL IMPACTS

To varying degrees fuel combustion produces *emissions* that variously warm the climate (GHGs) and have adverse health effects in high concentrations. Such emissions are increasingly being regulated, leading to significant changes in fuel use. Increasingly stringent agreements are being entered into on GHG emissions (e.g. COP 21[3]) and attention is being paid to cross-border GHG emitters in international air transport by ICAO[4] and international shipping by IMO[5]. Emissions with health impacts have historically been controlled locally, but these are increasingly being controlled nationally and internationally, e.g. vehicle emissions standards, sulphur in marine fuels.

Pricing of GHG emissions (cap and trade variants) is a common regulatory response. This increases the price of fossil fuel use, but the impact on markets is more complex as fossil fuel prices are much lower than viable alternatives. Despite COP21 being voluntary, shifts away from GHG-producing energy technologies are occurring and further policy responses to encourage this are likely. New Zealand has made specific commitments to reduce its domestic GHG emissions[6].

These environmental and other issues of sustainability are also leading consumers and governments to look at their own purchases. This translates into *emerging global market preferences for renewable fuels and sustainable goods and services*[7]. Demand and prices for fossil fuels and less sustainable products will reduce with important implications for New Zealand's exports such as food.

Because of these trends various major international organisations and governments are planning *larger investments in the development of cleaner technologies*[8]. The availability of this research and early stage funding has potential relevance for New Zealand researchers.

Finally, changes to the climate may impact regional availability of renewable energy resources, create risks to energy infrastructure, and change patterns of use.

POTENTIAL STRUCTURAL CHANGES IN GLOBAL SUPPLY AND DEMAND FOR FUELS

China's strong growth in energy demand, particularly coal, is levelling off because of lower economic growth and new investments in renewables and natural gas, partly reflecting concerns about emissions. In the same way shale gas is putting pressure on coal in the US[9], and low economic growth and power demand is impacting European demand. India and ASEAN remain the sources of growth for coal as they seek to address energy access and poverty reduction, but this should not support a return to the recent levels of high demand growth [6].

[3] http://www.un.org/sustainabledevelopment/cop21/, accessed 19 August 2017.
[4] https://www.icao.int/environmental-protection/Pages/default.aspx, accessed 19 August 2017.
[5] http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Default.aspx, accessed 19 August 2017.
[6] See http://www.mfe.govt.nz/climate-change/reducing-greenhouse-gas-emissions/new-zealand%E2%80%99s-post-2020-climate-change-target, accessed 19 August 2017.
[7] See for example [30] and https://www.credit-suisse.com/microsites/next/en/entrepreneurism/articles/millennials-drive-sustainability.html, accessed 19 August 2017.
[8] See for example Breakthrough Energy Ventures and the areas it has identified for investment http://www.b-t.energy/landscape/, accessed 19 August 2017.
[9] At the time of writing the long-term impact of the changes in US energy policies is still unclear.

At the same time coal prices are being impacted by the fall in *natural gas and oil prices*. Demand for these fuels has weakened but the major change has been the growth in non-OPEC oil production, particularly US tight (shale) oil. The long-term impact on oil prices remains unclear but it appears to be constraining prices.

For these reasons both the shift from coal and the relatively low prices for these fuels could well persist for much of the coming decade. While beneficial for global growth the low prices are reducing global investment in new sources of supply for these fuels, and also making *investments in substitute technologies less attractive* and *reducing the ability of economic instruments to manage GHGs*.

ENERGY TECHNOLOGIES

Materials science is enabling the design of new materials that have a range of novel properties, particularly at the scales where energy conversions take place [4]. This is introducing a wide range of new energy technologies.

Examples include Photovoltaic (PV) panels, LEDs, power electronics, sensors, batteries, phase change materials, catalysts, permanent magnets, and structural composites enabling larger wind turbines and high density flywheel storage.

ICT is changing both the energy sector and energy use. Smart grids, big data, analytics, demand side management, and the internet of things are all examples of the former, the way telepresence, artificial intelligence, and autonomous transport are changing transport energy use are examples of the latter. Many of the benefits ICT enables derive from the convergence of existing but previously independent systems.

Biotechnology is developing processes and organisms that show promise in the production and processing of biological materials for fuels and for cleaning up fossil fuel processes e.g. new organisms capable of cleaning up gas streams etc.

Meanwhile, ongoing improvements in traditional energy technologies are often drawing on results from these areas.

A common feature of new technologies is the time taken to get them to market, particularly those with potentially significant impacts [5]. On the basis of history most of the technologies that will be making a significant impact in the 2030s exist today. From New Zealand's perspective this means it needs to be realistic about where it can contribute at the more basic levels of research and the level of resources required to bring any consequent developments to market. History shows that international collaborators and commercial partners are required.

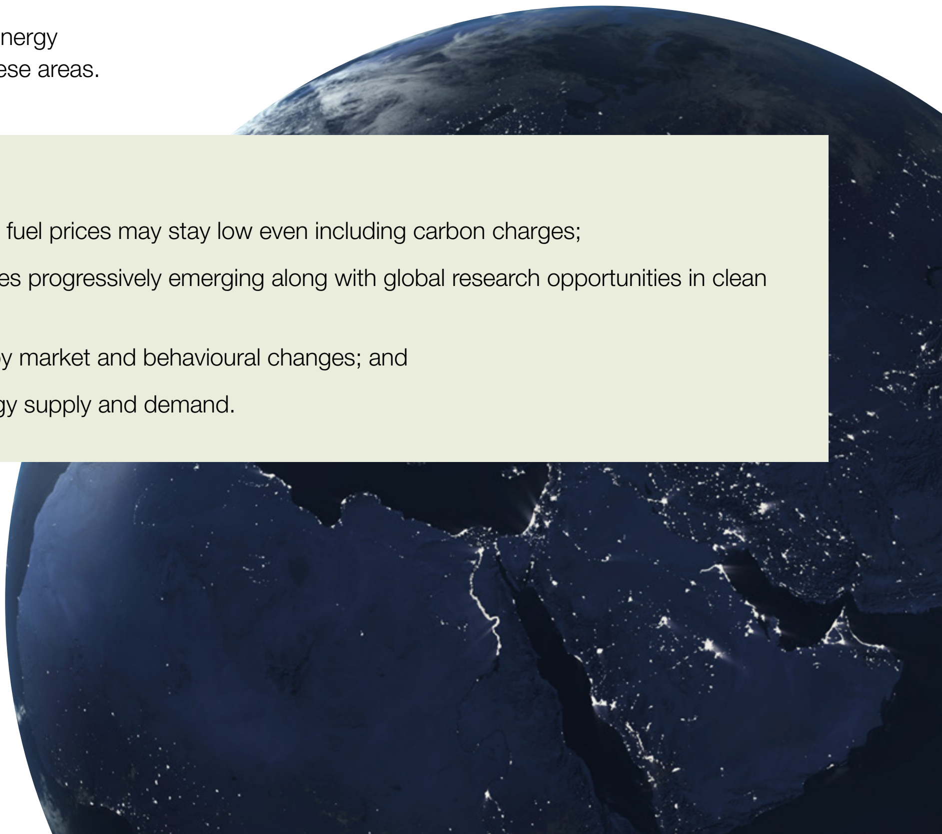
Many of the new technologies (e.g. ICT and materials) rely on economies of scope rather than scale. Consequently, they tend to have lower capital cost than many existing energy technologies. This will increase the sector's responsiveness to change. At the same time traditional monopolies will erode and their regulation will require change. New Zealand could see new business models emerge, potentially stranding assets.

A NOTE ON UNCERTAINTY, RISKS AND SHOCKS

There is significant *uncertainty* surrounding each of these trends. This in turn generates risks for New Zealand that require management.

Managing in uncertainty doesn't mean simply managing for the worst case. Doing so would risk imposing significant unnecessary costs. Instead, the objective should be to make New Zealand's energy sector better able to adapt to the foreseeable risks[10].

The underlying uncertainty itself will be complex, e.g. ranging from stochastic to progressively unfolding, and the methods for achieving resilience in light of this will also be complex. Local research will be required to properly understand these, the potential responses, and the ways the sector will change.



GLOBAL IMPACTS ON NZ

- Increasing regulation of dirty fuels, but fossil fuel prices may stay low even including carbon charges;
- Change from new and improved technologies progressively emerging along with global research opportunities in clean technologies;
- But even larger and faster changes driven by market and behavioural changes; and
- Significant global uncertainties in both energy supply and demand.

[10] The Ministry of Transport Real Options work programme provides a good background on the techniques of adaptive investment management as applied to the related field of transport planning [33].

THE NEW ZEALAND CONTEXT

New Zealand has some special attributes that modify global forces, and influence the future of its energy system and the derivation of economic, social and environmental value from it [7].

New Zealand is physically isolated, remote from its markets and dependent on air and sea transport for trade and travel. Long distance transport is a fossil fuel intensive activity. The isolation also means the scope of the energy system is limited to the movement of physical fuels across the borders. The electricity system cannot pool real-time supply and demand with other countries[11].

New Zealand's population is not large or dense on an international scale and it cannot achieve the economies of scale that other larger developed countries can. Being a small economy means that individual large energy users can have significant and potentially destabilising impact on the system (e.g. aluminium and methanol production).

All these factors give a relative global disadvantage in some areas of energy use, but when it comes to energy resources New Zealand's natural endowments more than compensate[12].

NEW ZEALAND'S ENERGY RESOURCES

New Zealand is a mountainous country sitting astride a plate boundary, spanning subtropical to cool temperate island climates. This provides a good range of natural energy resources:

1. **Hydro electricity**[13] provides 60% of electricity generation, but planning restrictions mean any potential expansion [8] at scale is unlikely to be acceptable[14];
2. **Geothermal** in the North Island and good **onshore wind** [3], [9] both have potential for significant expansion. Geothermal is the least-cost fuel for both base load electricity generation and for local thermal loads. New Zealand is one of a small number of countries with expertise in its exploitation and research into its geology is an important component in its energy research portfolio (see Appendix). Moreover, its use above ground (including low enthalpy systems) has potential for further development. Wind generation is cost competitive thanks to New Zealand's high capacity factor and the availability of significant hydroelectricity to manage its intermittency [3], but the necessary technology is imported;
3. **Oil and gas** (on and offshore). The oil is low in sulphur and high in wax and paraffins. New Zealand predominantly exports oil and gas and relies on imports to meet liquid fuel demand. Natural gas is reticulated in the North Island for industrial and domestic use and electricity generation. It is cleaner than coal and liquid fossil fuels, and has as compressed natural gas (CNG) been used as a substitute for petrol in New Zealand's transport fleet. Reserves to production ratios are average on an international basis [3], but investment in development is required to maintain production [10]. Significant energy research investment goes into both gas and petrochemical resources (see Appendix) reflecting their value to the New Zealand economy, so additional research ***is not*** a priority[15]. With geothermal growth, demand for natural gas in electricity generation has been falling, but it remains the least-cost fuel for mid-merit and peaking generation[16]. Under some circumstances it can become the least cost base load fuel for electricity generation [11];
4. **Coal** is affected by falling demand both in exports (premium bituminous) and the electricity sector (halved 2009/14), but demand is increasing in thermal industrial applications (mainly food processing) [12].
5. **Biomass** has considerable potential for expansion (for example [13]). At present only direct use of woody biomass for thermal loads in the industrial and residential (85:15

[11] Unlike most of the OECD NZ's currently lacks any capacity to export or import natural gas on any timescale, supply is buffered through some recently established underground storage and its use as energy or conversion to chemicals (e.g. methanol, urea).
[12] "New Zealand's residential electricity cost is within the middle of the OECD range. In contrast, industrial electricity costs are amongst the lowest across the OECD range." [1]
[13] Hydro and wind may both be impacted by changes in the local climate, but the significance of projected changes is unclear. [37]
[14] New Zealanders could be willing to see these reviewed in the face of significant shortages of clean energy.
[15] However additional research into their uses is proposed in light of risks from GHG emissions reducing the potential value of the resource (see later).
[16] Even CCGT baseload is cheapest on a range of natural gas and carbon prices. The use of take-or-pay contracts for natural gas encourages higher levels of use than would otherwise be expected. [3]

ratio) sectors is significant. Large scale users burn low value by-products as the fuel, predominantly in the Wood, Pulp, Paper and Printing industry. Otherwise biomass is competitive in niches e.g. heating homes and substituting for coal in industrial applications[17]. It is also economic at smaller scales using waste streams, but growth is limited by the poor supply of low cost feedstocks due to the related problems of lack of scale, the dispersed nature of the resource and an immature market with multiple participants. Converting biomass to transport fuels (liquid or gaseous) is uneconomic even at significantly higher fossil fuel prices/emissions charges than at present [14]. This is an area requiring technological advances to become economic. Options are discussed further in the transport context later in this report.

6. **Solar** suffers from intermittency and regional supply variations, so it needs to be used for loads that can be accommodated and/or coupled with storage (e.g. solar thermal, hydro, battery). Its time-of-day and seasonal[18] generation profile is counter-cyclic to both the national load profile and the dominant charging profile of Electric Vehicles (EVs). PV has a fixed balance of plant favouring larger installations but it is unlikely to be cost competitive over the next decade with wind or geothermal as a network based resource without a significant technology breakthrough. However, PV is being installed at a household/community level to deliver non-economic value by providing a level of energy independence and choice, fixing part of the energy bill, and contributing to cleaner energy consumption. There are niches where it is the most cost effective investment, e.g. remote houses.

To a greater or lesser extent the availability and cost of all these resources vary throughout the country and different mixes of resources apply in different regions.

Overall New Zealand has sufficient raw energy resources to meet its forecast needs, and where there are issues relating to their identification and extraction New Zealand has research investments addressing these (Appendix). The outstanding issue addressed in the balance of this report is ensuring that these energy resources are suitable to meet future demand.

NEW ZEALAND'S ENERGY RESOURCES:

- Significant natural supplies of raw energy resources;
- Existing research investments generally meet the expansion of the availability of these resources; and
- The outstanding issue is to how to make use of these resources to meet future economic, social and environmental needs.

[17] And even this can be hidden by distortions in the relevant markets, e.g. flat time-of-day tariffs in the electricity system conceals the potential advantage for domestic biomass heat in winter evenings.
[18] This can be minimised at some cost to the total annual generation by installing with a tilt angle that favours winter capture.

ENERGY USE AND THE ISSUES THAT ARISE

Sustainably increasing New Zealand's wellbeing needs access to relatively low cost clean energy, with a supply that is secure, resilient and that meets environmental objectives and obligations, while ensuring everyone's basic energy needs are met.

These are all relative measures with trade-offs between them. This strategy seeks to improve New Zealand's performance on each of them, but as a general principle the greater the supply of low cost, clean energy, the more options are available to manage future risks.

The Electricity Generation and Distribution, Transport and Industrial Processing sectors dominate energy consumption, and will be addressed below in more detail.

While of smaller scale the ***Residential*** sector raises social issues around access and vulnerability to change will then be discussed, and finally the document addresses where *Ongoing Research* in the energy sector is indicated.

A number of scenarios have been published [15], [11], [3], [16], [17] projecting how the New Zealand energy sector or aspects of it might develop. These typically make a basket of assumptions and project them forward, sometimes as much as 20–30 years[19]. They are useful inputs into understanding the consequences of trends.

This Strategy identifies the areas where New Zealand should actively manage the risks and exploit the opportunities, rather than simply assessing outcomes if trends continue.

Taking each sector in turn, the current dynamic within the sector, the consequent likely direction for development and the emerging risks and opportunities are as follows.

ELECTRICITY GENERATION AND DISTRIBUTION

Electricity consumption has been relatively flat across all sectors for the last decade [1]. Primary industries' use has had faster growth than average, while wood processing has declined, but neither trend is particularly significant in absolute terms.

The main demand uncertainty in the MBIE Scenarios [11] is the future of the Tiwai Point smelter. The impact of closing it (coupled with other low assumptions impacting demand growth) persists up to 2050 although the long-term impact is probably exaggerated by the way the scenarios are constructed.

This is an extreme example of the challenges in managing large industrial loads [18], [9]. A major component of the risk is the uncertainty this creates for investment in the electricity sector and the consequences if these are misjudged.

However, to the extent that local research can assist it would be commissioned by the electricity industry and major users, and this should be encouraged.

The other MBIE scenarios up to 2050 are much closer together, particularly given the timeframes and uncertainties. New Zealand has adopted greater use of market mechanisms and private sector involvement in its electricity sector when compared with many other countries. This is an advantage in an uncertain environment and means it is likely to be able to adapt under business-as-usual to the projected range of demand.

There are risks if regulation fails to keep pace with the changes [9]. The most significant foreseeable risk is that increases in storage capacity in the transmission [19] and distribution systems[20] and peer-to-peer trading[21] will undermine the

[19] The uncertainty inherent in the scenario projections, even accepting the assumptions they are based on, means they are best regarded as only indicative on these timeframes.
[20] The impact on local distribution companies will be seen even before it impacts on the grid.
[21] See for example the Electricity Authority report on the 2016 ACCC/AER regulatory conference in Brisbane https://www.ea.govt.nz/about-us/media-and-publications/market-commentary/events/new-market-commentary-article/ accessed 19 August 2017.

network natural monopoly assumptions in the regulatory framework. These changes break down the real-time supply link from generator to customer and power quality management becomes increasingly decentralised [19]. The distribution system's imperative in managing the network from a generator to the local storage changes from reliability (no outages) to resilience (rapid restoration). This will be potentially disruptive, not only to the current network monopoly and commercial arrangements in the sector, but also to stability of supply. Industry reform and tariff changes will be required if New Zealand is to exploit the opportunities that arise [20].

New Zealand's situation is unusual, being an isolated system with high levels of renewables and market based regulation. *This makes the evolution of changes such as these and their impact a priority for local research* [9]. Some funding of this research could be expected from the regulators and the industry, but the impact is likely to go beyond their current interests.

There are aspects of demand growth in the MBIE scenarios that are increasing environmental risks. Peaks in intra-daily and inter-seasonal loads have been increasing [3] and are projected to continue to grow faster than average demand [18]. While hydro storage can manage a certain level of peaks this is now largely exhausted [3] and so, unless alternatives can be found, the need for fossil fuel generation will grow to service these peaks [21] (Appendix C, Vol.1). All the MBIE scenarios add significant new gas peaking generation over the next decade[22]. This increases emissions[23]. In a similar way dry year support also requires fuelled generation.

New Zealand can change this, particularly if it focuses on displacing these new investments. A low emissions mixed hydro, geothermal, and wind generation system with greater flexibility (e.g. in lake storage) could cope with some increase in peaks. But the main research opportunity is to find ways to flatten the load serviced by the grid and identify other measures to cope with dry years thereby reducing the need for fossil fuel generation.

There are many opportunities to do this, supply side and demand side, centralised and decentralised. Some aspects of business-as-usual will move in this direction, for example supply side storage and switching to biomass, and time-of-day pricing[24] will influence demand particularly with emerging more flexible loads such as EVs [21]. But this is an area where the benefits of low-cost load sculpting are high in terms of reducing exposure to GHGs and there are multiple options that include both thermal and electrical energy and potential behavioural changes. *This makes the identification, assessment and development of low cost opportunities that go beyond business-as-usual priorities for local research*.

Much of the peak arises because of residential demand, so household behaviours will form an important part of this.

Finally there will be a significant increase in demand for electricity, particularly as the number of EVs increase. Current wind and geothermal resources can service this load and both have potential for improvement. In the case of wind New Zealand will import technologies from overseas. However there is still an opportunity to *increase the availability of low cost, cleaner, geothermal energy for both electrical and thermal loads*[25], and this is less likely to be able to be sourced internationally. In the case of prospecting and extraction there are currently research investments in place so the priority is above ground.

ELECTRICITY SECTOR R&D

- Maintain a stable and secure electricity supply in the face of technologies and consumer behaviours that might disrupt it.
- Develop low cost, cleaner ways to reduce peak demand on the grid, and explore cleaner options for dry year support.
- Increase the availability of even lower cost, cleaner, geothermal energy for both electrical and thermal loads.

[22] Further out base load gas generation additions occur in some scenarios, and to the extent that lower cost geothermal can be achieved this can be avoided.
[23] The Vivid Economics report [9] puts aside the need for supply and demand profiles to match and the consequences of this, and therefore doesn't address this issue.
[24] For example, Flick Electric Co.
[25] Increasing the use of geothermal for thermal loads will still free up other generating resources.

TRANSPORT

Transport represents about half New Zealand's energy use if international transport is included (Table 1).

Demand had been relatively flat for the decade to 2015 [12], reflecting the relatively flat overall vehicle kilometres travelled (VKT) [16], but 2015 saw 3% growth.

While VKTs by light passenger vehicles have declined, light commercial and truck VKTs have grown; the former faster than GDP. However, there has also been a decline in domestic aircraft kilometres travelled, albeit with increasing passenger kilometres. As a consequence, within the flat demand for domestic energy, diesel use has grown 14% while petrol and avgas use have declined [12].

On the local supply of fuels to international transport, fuel oils have been flat while avgas has grown, but only to keep pace with GDP despite faster growth in trade volumes.

This paints a general picture of both improved use of transport to support GDP and better use of energy within transport. However, over the last few years improvements in the fuel efficiency of new light vehicles has not improved, reflecting a trend to larger vehicles (e.g. SUVs). Population growth has also reduced the impact of improved efficiency.

Encouraging both productivity and energy efficiency improvements will be mainly business-as-usual (whether road, rail, sea, or air), despite the uncertainty in how demand for transport will evolve (e.g. autonomous vehicles). To the extent policy issues are involved the public agencies can be expected to commission the necessary research.

Managing GHGs, and other emissions risks, requires responses that go beyond business-as-usual. Transport relies upon low cost and easily deployed energy-dense fuels. Fossil fuels are highly competitive on each account. Their use dominates the New Zealand fleet and their emissions dominate total emissions from energy use.

The main options for managing this are:

1. moving to more efficient, lower emissions, conventional powertrains;
2. adopting cleaner alternative powertrains and fuels[26] and reducing demand for transport; or
3. finding significant offsets for GHGs to meet treaty commitments and market expectations[27].

In what follows we will focus on the second option. The first and third are set aside as either simply business-as-usual (e.g. importing more efficient vehicles; carbon sinks; carbon credits) or beyond immediate time horizons (e.g. carbon capture and storage [15]).

Sourcing new alternative fuel vehicles at the scale of the New Zealand transport fleet and establishing the necessary fuel supply chains[28] and production systems will be a local problem and not without significant risk, even if addressed over decadal timescales. This can always be achieved at a cost, but New Zealand will want to be prudent in so doing because both the risks and the best means to manage them are uncertain and progressively unfolding.

Internationally a number of ***cleaner fuel systems*** are close to or in market: battery electric, fuel cell electric (usually hydrogen fuelled), hybrid varieties of both of these, compressed and liquefied biogases, and liquid biofuels (including alcohols) often used as fossil fuel blends.

However alternative gaseous or liquid fuels are unlikely to be able to compete with fossil fuels, even at foreseeable charges for GHG emissions[29]. Their feedstocks face competition for scarce resources such as land and water and have higher value in other uses (e.g. pulp logs, whey). Production and refining systems are novel, risky and expensive, particularly getting to the scale required, although these risks can be reduced with drop-in fuels that use existing supply chains[30].

In terms of risk management it is the lower risk, high payoff, options that will be the priority for early action. Where the alternatives are uncertain and the risks are high this argues for undertaking research targeted at risk reduction. With this in mind through to 2030 it is the low duty cycle fleet that offers the best prospect to introduce cleaner fuels, while the high duty cycle[31] fleet (domestic and international) needs to be the target for further research.

EVs AND LOW DUTY CYCLE TRANSPORT

In New Zealand electricity is the one fuel that is low cost, predominantly clean, potentially available in the volumes required to power the transport fleet[32], and has an existing national distribution network. EVs, including hybrid EVs, are becoming available in volume at prices that make their lifetime cost competitive in New Zealand with fossil fuel vehicle based transport [21]. When coupled with low cost clean electricity

[26] The option of removing GHG from the emissions is not practical in most transport applications.

[27] Offsets may, however, be insufficient to effectively manage the risks to trade and tourism from customer perceptions of the use of dirty fuels.

[28] Continuing to import fuels from more efficient producers remains an option.

[29] As noted earlier CO2-e charges of up to NZ$1,000 a tonne could be required to make drop-in biodiesel economic if the barrel price remains below ~US$70.

[30] However, where the engines require highly engineered fuels (e.g. modern internal combustion engines, aircraft) suitable alternative fuels are likely to be more difficult and expensive to produce.

[31] In discussing EVs the main constraint is range so vehicles that are used for short trips with reasonable stops (i.e. have a "low duty cycle") can be recharged regularly. These will be the best prospects for EVs. Note, some will be heavy vehicles e.g. urban public transport fleet.

[32] A key advantage over other fuels is the efficiency of the distribution and use of direct electricity. Including distribution ICEs get around 25% of their fuel's energy to the road, electric motors around 70%. There are additional losses in fuel delivery and battery storage but all told no more than half of the energy used in the existing transport fleet would be required in electricity generation to replace it – a 30% increase in current electricity generation would service half of New Zealand's domestic transport. Fuel cells using hydrogen from electricity are much the same as ICEs [34].

Zero emission Framo E-Truck electric truck

they will reduce emissions at little, if any, increased life-time cost. They will be significantly cheaper and less risky than liquid or gaseous biofuel alternatives in this market segment.

For these reasons, some peculiar to New Zealand, shifting to EVs for low duty cycle transport is relatively low risk [9]. Over time it would not be unreasonable to see half the road transport fleet replaced by them[33]. The main risks lie in limited range (because of battery weight and cost); the time taken to recharge[34] (delivering high bursts of power from the grid is not cheap[35], although it's expected that the dominant form of charging will be low volume, overnight, at home[36]); actual price-performance of EVs in volume; and the time it will take to turn over the fleet, particularly where half of it is purchased second-hand from Japan [22].

Policy responses, rather than in-depth local research, should be adequate to manage the risks associated with the transition. The likely trends to more efficient use of each vehicle[37] and new technologies that encourage sharing means the fleet should be smaller and better used in the future [23]; both factors speeding the transition. The various New Zealand energy scenarios [11], [15] assume low displacement rates, but the policy objective should be to accelerate this [9].

On the range and charging risks New Zealand will be predominantly a technology taker. However, there are two critical areas where New Zealand has international research capability. These are in dynamic charging (allowing charging while in transit) and high energy storage with fast release. ***Investing in these charging technologies will help reduce the risks New Zealand may face as an early adopter***, as well as extend the potential application of EVs into vehicles with higher duty cycles.

A complementary approach to the low duty cycle fleet is to increase the use of biofuels as blends, particularly bioethanol with petrol and biodiesel blends derived from fats and oils. While more expensive to produce these are currently sold in New Zealand, but expanding volumes beyond business-as-usual will require either imports of sugar cane bioethanol or advanced biofuels. Either would also assist with the higher duty cycle vehicles and the prospects for supplying these competitively in New Zealand (or by way of import) should be included in research looking at alternative futures for this fleet (below).

Finally, there appears to be a shift from land based logistics for some goods to drone based, although this may be limited to countries with higher urban population densities[38]. If the uptake is significant this may have an impact on the future energy needs of the sector. Drones will face different constraints on the preferred power trains and fuels from land based vehicles, but will mainly compete in the low duty cycle segment of the market.

[33] Light vehicles (but not the same as low duty cycle vehicles) constitute almost all the petrol use and half of diesel use [1]

[34] New Zealand's 240/400V distribution system allows faster charging than for example in North America and Japan, but this is still significantly slower relative to petrol.

[35] See https://actu.epfl.ch/news/charging-an-electric-car-as-fast-as-filling-a-tank/, accessed 1 January 2017, for a description of the issue and the use of battery banks to solve it.

[36] This will depend on the popularity of transport-as-a-service where charging the fleet becomes the issue.

[37] For a discussion of this potential trend with Generation Y in New Zealand (although based on a small sample) see [36].

[38] For example, see https://www.amazon.com/PrimeAir (accessed 19 August 2017)

HIGH DUTY CYCLE

The future of the rest of the transport fleet, the high duty cycle component (including road, rail, sea and air), is not so clear-cut. Large reductions in emissions through cleaner fuels appear costly and the best solutions uncertain. Any prospective fuels for the high duty cycle fleet need to be high density to service high fuel consumption and avoid displacing payloads.

New Zealand's low population density works against high capital cost solutions like electrification of longer distance transport. Battery weight, and the costs of regular charging, means electricity has diminishing returns, although hybrids are on the drawing boards[39]. Higher energy density biofuels will be suitable, but second generation/advanced biofuels (or imported sugar cane fuels) will be required in order to get the volumes to have an appreciable impact on emissions.

Demand for dirty fuels will reduce through ongoing efficiency improvements [24] and the substitution of low fuel use alternatives to transport. These two approaches are likely to be the most cost effective ways to reduction emissions over the next 10 or so years [25].

But there will be shorter-term prospects for alternative fuels. The investment risks in longer-term post-2030 opportunities can be being reduced in the interim. There will also be the potential to recover higher costs from customers willing to pay a premium for clean transport.

New Zealand will have limited control over the fuel systems that get adopted in sea and air transport services (e.g. biofuels and hybrids [26]), but the local price of the necessary fuels will impact on international competitiveness. This is occurring with the International Maritime Organisation's (IMO) decision to implement a global sulphur cap of 0.50% in marine fuel oil (MFO) in 2020[40]. The Marsden Point refinery appears unable to supply this without significant upgrading. The alternative is to import low sulphur MFO, but regardless New Zealand will be facing significant price increases. This will make shipping less attractive and New Zealand less competitive, but alternative fuels will potentially become more attractive.

Through to 2030 there may well be increasing consumer willingness to pay for clean fuel for freight and air travel (particularly tourism). This could strengthen the case for early local production of drop-in bio jet and bio MFO to fuel a subset of trips, even if they remain uneconomic more generally. These could exploit some of the lower cost feedstocks that are only available in low volumes.

There will be more flexibility with land transport, because both the types of engines and fuels will be able to be changed in these timeframes. However New Zealand will still be selecting from engine systems being developed and supported internationally.

The main New Zealand transport operators are medium-to-large companies but even for them establishing new low cost fuel supply chains will be risky[41]. The Government could share some of the risk as it has interests in meeting international obligations as well as in mitigating the economic and environmental impacts of emissions.

Investing in research into the options for New Zealand's high duty cycle transport sector is likely to be of significant value. This would include better understanding of the collective uncertainties and risks, and, where indicated, into the de-risking of key developments for New Zealand.

That research needs to cover both the development paths for vehicles and potential low-cost cleaner fuels, and the ways logistics and travel and other drivers of fuel demand are changing. Cleaner fossil fuels as well as biofuels should be included [15]. Integrated vehicle and fuels roadmaps are appearing internationally and New Zealand should be building on those for land transport [25] [27], adjusting for New Zealand's situation, and where possible joining those that deal with international marine[42] and air [26][43,44].

FACTORS INFLUENCING DEMAND

As the Ministry of Transport notes [16], transport meets New Zealand's basic need for access and there are various other ways for people to achieve this (particularly through better communications and closer proximity). There is therefore some ability to substitute between these. This has implications for energy use and the impact is potentially more significant and occurring faster than fuel changes.

ICT and related technologies are bringing rapid change to transport-as-a-service, trip optimisation, and trip substitution and each is delivering access using much less energy. Given New Zealand's particular exposure to long distance transport this is an area that is likely to be a source of significant value to New Zealand, even putting aside emissions risks.

[39] For example, Nikola Motors. Wrightspeed Powertrains and Infratil are deploying gas turbine electric hybrids in the Go Bus fleet, although these are largely lower duty cycle vehicles, see http://www.nzbus.co.nz/news-from-nzbus/media-release-nz-bus-investing-in-electric-powered-vehicles, accessed 19 August 2017.

[40] http://www.imo.org/en/MediaCentre/PressBriefings/Pages/MEPC-70-2020sulphur.aspx, accessed 13 January 2017.

[41] In many cases the actual vehicles are owned by small owner-operators.

[42] There is limited activity at the industry level in international marine but this may be changing, see http://www.imo.org/en/MediaCentre/PressBriefings/Pages/28-MEPC-data-collection--.aspx, accessed 13 January 2017.

[43] New Zealand researchers are already involved with NASA and this should be encouraged.

[44] Fuel-specific activities (e.g. IEA Biofuels and Scion's Biofuel Roadmap) will provide input into these processes across all modes.

In the main New Zealand will remain a technology taker and these technologies will be implemented under business-as-usual, *but New Zealand has capability in aspects of ICT developments and this offers international leadership opportunities, with a particular niche being applications of telepresence, remote sensing and AR/VR*. This should rapidly and cheaply provide more efficient and cleaner alternatives to travel and particularly help to address distance as a barrier for New Zealand's businesses. Research in this area should also address the impact of these technologies on the transport sector, and tourism and trade.

The built environment is unlikely to be a factor that changes rapidly, although new communications technologies will have impacts on where businesses operate from and people live. Issues such as urban planning, population densities, and their impact on demand for transport should be manageable under business-as-usual[45].

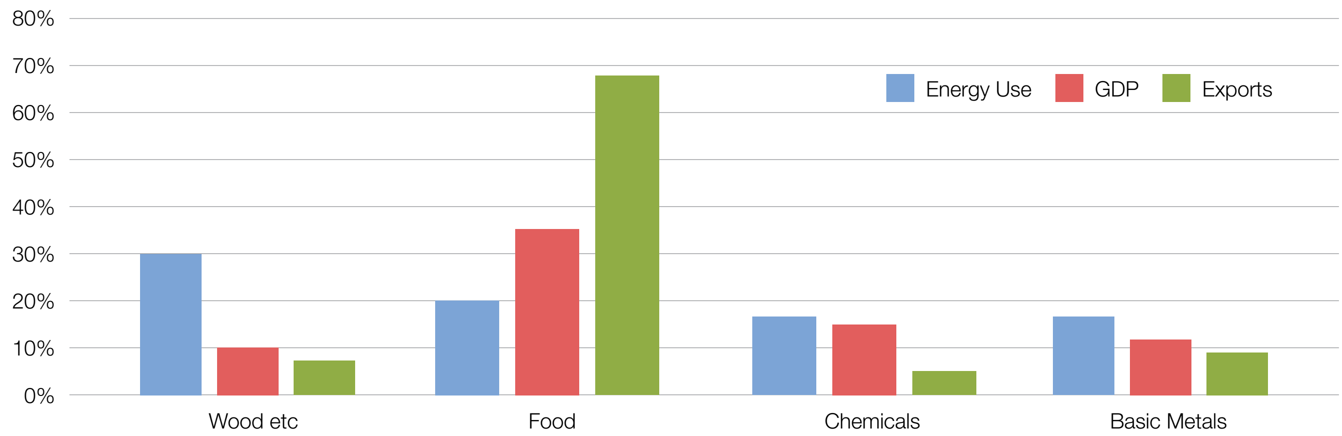
TRANSPORT SECTOR R&D:

- Develop charging technologies, based on NZ's international capability, to assist the introduction of EVs and extend their range;
- Assess the options for high duty cycle transport in NZ (both vehicles and fuels) and the implications, along with the future of logistics, and undertake risk reduction where indicated; and
- Develop ICT applications, based on NZ's international capability, to reduce New Zealand's energy intensity and exposure to distance, with particular emphasis on telepresence, remote sensing and AR/VR.

[45] Even if this appears to be difficult in practice.

INDUSTRIAL PROCESSING

TABLE 2: PERCENTAGE OF INDUSTRIAL PROCESSING SECTOR



Industrial Processing (including coal for steel) is 37% of total consumer energy; 13% of GDP and 56% of exports.
Sources: Energy Use 2015 [12]; GDP and Exports 2013 [28]

Four subsectors: Wood, Food, Chemicals, and Basic Metals dominate energy use in the industrial processing sector, accounting for 80% of demand.

The largest energy user is Wood, Pulp, Paper and Publishing. The exact figure isn't reported because the use of wood as a fuel isn't formally allocated to subsectors, although elsewhere [29] virtually all of it is reported as being used in this subsector. On that basis wood provides close to 75% of the subsector's energy, and the subsector uses more energy than the whole Commercial sector, and is similar in use to the Residential sector. Total energy use has been relatively stable over the last decade.

This use of waste points the way to a potential new industry sector, a bio-chemicals industry analogous to the petrochemicals industry. The lesson from the economics of biofuels production is the need for the fuel to be a relatively low value co-product within a range of higher value products. Meeting the needs of New Zealand's high duty cycle transport fleet for fuels will only likely be possible in this way. This could be a potential development from the existing wood processing industry. *Exploration of new products (including biofuels), processes (bio-refineries), supply chains and markets for a potential bio-chemicals industry will be valuable*.

The Food Processing subsector's total energy consumption is now ranked second. It has grown 80% over the last decade, predominately for milk drying, and this growth has been serviced about 50:50 by coal and natural gas.

The Basic Metals[46] and Chemicals subsectors use similar amounts of energy. Basic Metals has been relatively stable over the last decade. Its use is dominated by electricity (Tiwai Point aluminium smelter) and coal (Glenbrook). Chemicals' energy use is dominated by natural gas both as a feedstock and fuel. This is particularly sensitive to the levels of methanol production which has increased since 2012, reaching a peak in 2014 but dropped back in 2015 with Methanex having production problems [1].

These subsectors are dominated by a small number of large companies, and this can create risks, as has been already been briefly discussed in relation to Tiwai Point. But this also means that they and the energy industry should manage most of these potential risks and opportunities under business-as-usual. The extent to which there are country risks these will need to be addressed by the government. These subsectors are also the dominant users of medium to high grade heat where the alternatives to fossil fuel are currently limited [9].

The industry should be encouraged to undertake research into the options for managing all these risks within the New Zealand context.

The high energy use by these subsectors means they have among the highest embedded energy in their output (particularly if related transport is included), and are therefore sensitive to changes in the energy sector, and vice versa. However, the products are mainly high volume commodities that have to compete internationally on price, so energy efficiency is an important part of their profitability and receives close attention.

Table 2 also shows the percentage of the Industrial Processing subsectors' GDP and Exports contributions. On both measures the energy going into Food Processing has a relatively higher return compared with the other subsectors.

[46] This includes coal used as a source of carbon in steel production.

The Food subsector is important to the New Zealand economy and has been growing. It is one area where energy consumption has increased significantly and with its exposure to fossil fuels. Otherwise New Zealand's economy has been diversifying into lower energy use service activities. Adding to this exposure the Food value chain not only covers processing, it includes significant energy use in primary production and transportation.

New Zealand is one of the most efficent producers of animal proteins in the world, but the need to maintain that position has encouraged the use of low cost inputs. It may be difficult to adjust this business model to one that requires more expensive energy inputs.

There is a risk for consumer products, like commodity foods, that rely upon significant embedded low cost fossil fuels. Consumer sentiment can turn away from them, reducing margins to current producers, but allowing higher prices for new products that use more expensive but cleaner energy [30]. New emerging food technologies could assist this transition by reducing the amount of energy needed in production, but these technologies (e.g. protein from plants) may also help New Zealand's competitors.

New Zealand needs to manage these risks by developing food markets where clean energy earns a premium, and the products and supply chains to service them. The large-scale food processers should be capable of making that transition, but a potentially rapid shift in market sentiment may well be disruptive of many smaller producers and their supply chains. Solutions may also require collective responses. This is an area that warrants local medium-term research to help manage the risks and opportunities.

Encouraging growth in clean products is of general value to reduce the risks from emissions. The Chemicals sector, in particular, transforms fossil fuels into other products, and if the carbon in these could be fixed throughout its lifecycle it would be possible to exploit the fossil fuel resource rather than have to write off the investment in it[47,48]. *Local medium-term research into potential new low emissions products and processes for the petrochemicals industry will be of value*. This could include risk reduction around carbon capture and storage; although the economics of this for fuel production (for example) suggests this won't be a major contributor for 20-30 years [15], although large industrial point source emissions are potentially easier to manage. While these technologies are more likely to be developed internationally and/or by existing members of the local industry, there is significant value in these resources and some local effort is warranted.

INDUSTRIAL PROCESSING SECTOR R&D:

- Explore new products (including biofuels), processes (bio-refineries), supply chains and markets for a potential bio-chemicals industry;
- Develop food markets where clean energy earns a premium, and the products and supply chains to service them, and
- Investigate new low emissions products and processes for the petrochemicals industry.

[47] For a relatively local example see the Hazer Group (www.hazergroup.com.au) process developed by researchers at the University of Western Australia that is intended to produce hydrogen and graphite from Natural Gas with negligible CO2 emissions.

[48] This reduction in demand for fossil fuels will also come from other sectors e.g. the uptake of autonomous electric vehicles.

RESIDENTIAL

This sector is a large user of electricity (30% of the total electricity consumption) and particularly contributes to the morning and evening winter peaks with thermal loads (heating and cooking). It has a large part to play in moves to reduce these peaks. The progressive introduction of EVs and new transport and access technologies will have a particular impact on the residential sector's use patterns. These changes may have different impacts on different sections of the community and this will need to be managed to avoid adverse effects [17].

Consideration of these impacts will need to be part of any energy research programmes addressing them, but managing the peak domestic demand raises specific issues. The winter peaks are when New Zealanders who find energy difficult to afford most need it to stay warm and dry. Many live in poorly insulated rented properties and have limited flexibility to change their energy use and will be late adopters of new energy technologies, including EVs. Much has been done, particularly to the historic energy inefficiency of housing stock [7], *but New Zealand needs to find further low cost ways to keep its housing stock (particularly rentals) warm and dry, and to ensure that changes in the energy sector don't further adversely impact these consumers*.

RESIDENTIAL SECTOR R&D:

- Develop further low cost ways to keep homes, particularly rentals, warm and dry, and assess the impacts of other changes in the energy sector to avoid adverse impacts on the less well off.

SYSTEM-WIDE

There is considerable uncertainty in the energy sector. Technology is changing rapidly, geopolitical forces around energy supply and demand are unstable, significant environmental risks from its use are emerging, and societal reactions to these changes are significant.

While this Strategy has identified the main issues, new risks and opportunities are emerging, and on short time scales relative to the timeframes of the research being discussed. New Zealand needs to be monitoring international developments in both technologies and markets to assess the long term impact.

It will therefore be prudent to have a programme of horizon scanning – monitoring these trends, modelling impacts, and increasing the understanding of how the New Zealand energy sector is likely to respond [17]. *Systematic monitoring and an improved understanding of the New Zealand energy sector, focusing on the risks and opportunities, and taking account of the changing environment, is essentia*l.

As new risks and opportunities emerge that are beyond business-as-usual so new areas of research will emerge. Also the results of new and existing programmes of research will inform further research, and there will be a need to develop an evaluation framework to ensure research investments are effective[49].

This provides the basis for keeping this Strategy current.

The considerable change in the international energy sector creates emerging opportunities for New Zealand's internationally competitive energy researchers to attract research activity to speed addressing local problems [17] and to build international economic activity. These include previously mentioned niches such as geothermal, behavioural and markets, AR/VR, inductive power transfer, biofuels and foods. Others range over areas as diverse as market based regulatory frameworks, managing with high levels of renewables, and materials science to improve electrochemical reactions and superconducting power systems equipment. Investment is essential ***to grow NZ's internationally competitive niche energy R&D capabilities*** to help address local issues and to exploit the potential commercial prospects this brings.

SYSTEM-WIDE ENERGY R&D:

- To systematically monitor and improve understanding of the New Zealand energy sector focusing on risks and opportunities and taking account of its changing environment; and
- To grow NZ's internationally competitive, niche, energy R&D capabilities.

Chartered Accountants Australia and New Zealand Hologram: Shotz Ltd production and photo, www.shotzproductions.co.nz

[49] This in practice requires a wider framework for review of energy R&D within which this Strategy would sit, e.g. [35]

CONCLUSIONS

This Strategy has identified the main priority issues faced by the energy sector where medium-term research in New Zealand will assist in response. In summary these are:

ELECTRICITY GENERATION AND DISTRIBUTION

- Maintaining a stable and secure electricity supply in the face of technologies and consumer behaviours that might disrupt it.
- Developing low cost, cleaner ways to reduce peak demand on the grid, and explore cleaner options for dry year support.
- Increasing the availability of even lower cost, cleaner, geothermal energy for both electrical and thermal loads.

TRANSPORT

- Developing charging technologies, based on NZ's international capability, to assist the introduction of EVs for higher duty cycles.
- Assessing the options for high duty cycle transport in NZ (both vehicles and fuels) and the implications, along with the future of logistics, and undertake risk reduction where indicated.
- Developing ICT applications, based on NZ's international capability, to reduce New Zealand's exposure to distance, with particular emphasis on telepresence, remote sensing and AR/VR.

INDUSTRIAL PROCESSING

- Exploring new products (including biofuels), processes (bio-refineries), supply chains and markets for a potential bio-chemicals industry.
- Developing food markets where clean energy earns a premium, and the products and supply chains to service them.
- Investigating new low emissions products and processes for the petrochemicals industry.

RESIDENTIAL

- Developing low cost ways to keep homes, particularly rentals, warm and dry, and assess the impacts of other changes in the energy sector to avoid adverse impacts on the less well off.

SYSTEM-WIDE

- Systematically monitoring and improved understanding of the New Zealand energy sector; focusing on risks and opportunities and taking account of the changing environment.
- Growing NZ's internationally competitive niche energy R&D capabilities.

In this way the Strategy is the first step in developing an energy research programme for New Zealand. While there may be some differing views on priorities and coverage, and new issues and areas will arise, it is intended as living document, and such changes will need to be accommodated over time.

With these caveats in mind, the next step is for the relevant researchers and stakeholders in each of these areas to develop more detailed research programmes to address the relevant issues, and to attract investment into the programmes and get them underway. In some areas it may also be necessary to build research capability either by local development or partnering international.

NERI is looking to work with all stakeholders to assist this process to unfold.

APPENDIX: STOCKTAKE OF GOVERNMENT INVESTMENTS IN ENERGY R&D[50]

ENDEAVOUR FUND

(Vote: Business, Science and Innovation)

Title (summary)	Organisation	$m (incl)	Start	End	p.a. $m	Comment
Gas hydrates	GNS	3.7	10/12	9/18	0.6	Towards exploration drilling
Atlas of petroleum prospectively	GNS	2.3	10/14	9/18	0.6	Oil and gas
Tectonic transitions	UoW	2.8	10/15	9/19	0.7	Oil and gas
Petroleum source rocks	GNS	11.0	10/15	9/19	2.8	Oil and gas
Wood-energy investment	Scion	4.3	10/14	9/18	1.1	Waste wood and geothermal
Renewables and the smart grid	UoC	7.3	10/12	9/18	1.2	GreenGrid EPECentre led
Local demand control of electricity	UoA	2.7	10/15	9/19	0.7	Improve power system resilience to fluctuating loads by demand control
Solar redox flow battery	UoC	1.2	10/16	9/19	0.4	Primarily residential electricity with hot water co-gen
Geothermal silica deposits	VUW	3.7	10/16	9/20	0.9	Improving yields by allowing higher temperatures.
Discovering petroleum	UoC	1.1	10/17	9/20	0.4	Associated with buried volcanoes
Increase use of Geothermal	GNS	7.2	10/17	9/22	1.4	New Integrated Geoscience Methods
Hybrid-electric aircraft	VUW	7.2	10/17	9/22	1.4	Ultra-high speed superconducting machines
Charging for electric vehicles	UoA	13.6	10/17	9/22	2.7	Inductive Power Transfer pavement systems

Approximately $14.9m p.a.

STRATEGIC SCIENCE INVESTMENT FUNDING

(Vote: Business, Science and Innovation)

Investments are not yet reported at a level to allow allocation to sectors. Historically GNS had $7.2m p.a. allocated to energy resources and sustainable energy and Scion had $3.5m to energy security. NIWA included growing renewable energy production as one of its 6 outcomes but below that level the main emphasis is on understanding the resources with no targeted energy programmes.

NATIONAL SCIENCE CHALLENGES

(Vote: Business, Science and Innovation)

Two Challenges could have been expected to include an Energy component: Science for Technological Innovation and Building Better Homes, Towns, and Cities (BBHTC). As things have turned out STI only has a <$0.5m p.a. allocated in the Analytics focus area for electrical systems, and the proposal just submitted for BBHTC lacks any significant component dealing with energy (Scion is contributing $200k core funding that includes energy technology solutions, there is existing involvement with IEA EBC Annex 66 Occupant behaviour, and the project tables suggest probably no more than 0.1 of an FTE devoted to energy related matters).

CENTRES OF RESEARCH EXCELLENCE

(Vote: Tertiary Education)

Only MacDiarmid has a significant programme on energy related matters – Materials for Energy Capture and Utilisation. This could amount to $1m p.a. Te Pūnaha Matatini and Dodd-Walls are in related areas, but aren't active in energy specifically. The Riddet Institute is the future foods CoRE but it has no programmes specifically focused on energy inputs.

The above stocktake comes to around $27m p.a. Government investment in Energy R&D excluding close to market grants. This compares reasonably with the amounts returned to the IEA for Government RD&D of $21m for 2011 although a detailed reconciliation has not been attempted. The 2014 public expenditure was the lowest in the IEA and third lowest as a ratio to GDP [2].

[50] Only medium-term energy sector directed investments i.e. excludes investments for other reasons e.g. education (PBRF) and pure research excellence (Marsden).

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