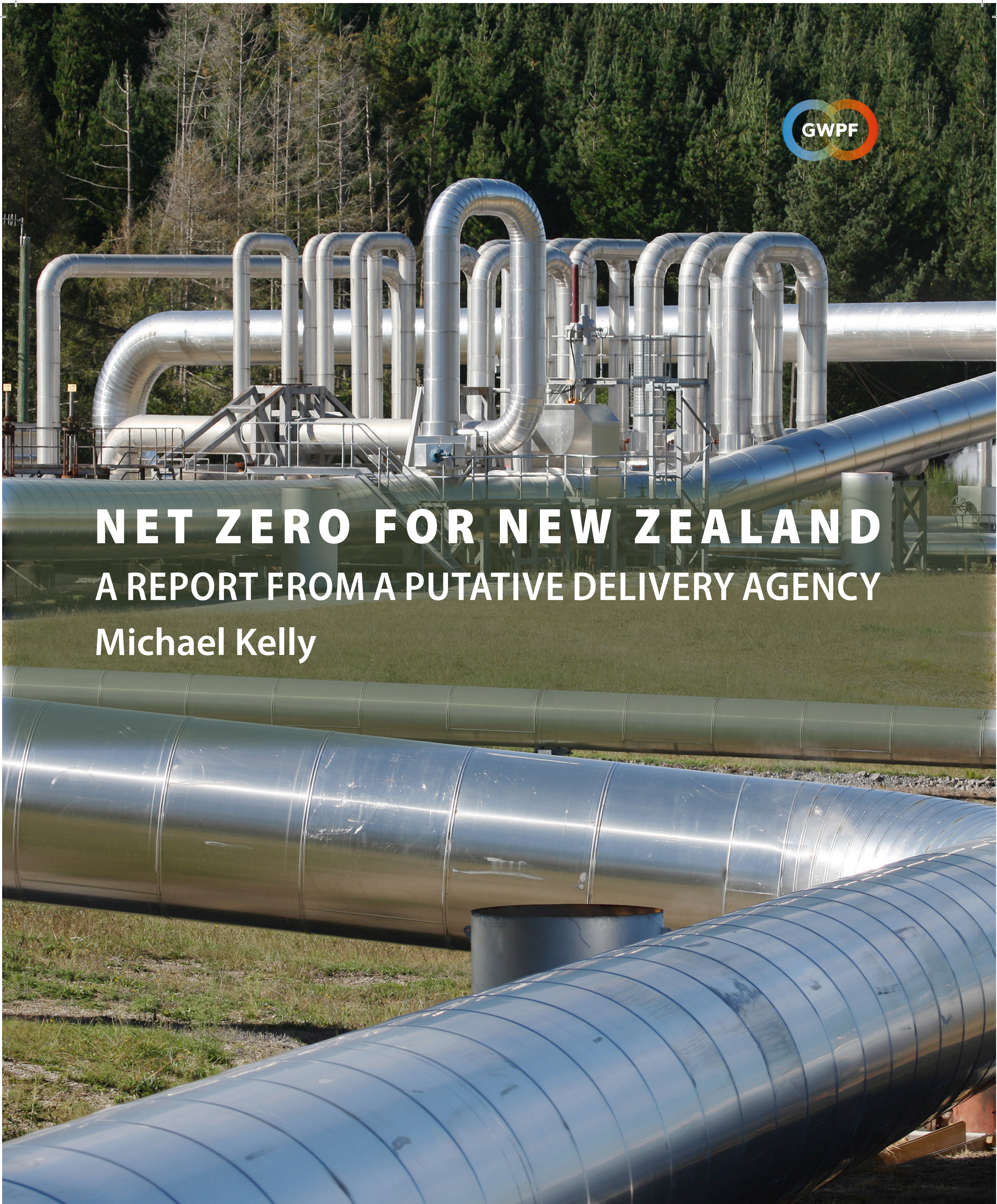

NET ZERO FOR NEW ZEALAND

A REPORT FROM A PUTATIVE DELIVERY AGENCY

Michael Kelly

The Global Warming Policy Foundation
Note 31

Net Zero for New Zealand: A report from a putative delivery agency

Michael Kelly

Note 31, The Global Warming Policy Foundation

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About the author

Michael Kelly, a New Zealander, ended his academic career as the inaugural Prince Philip Professor of Technology at the University of Cambridge. His main research focus was in new semiconductor physics and technology for ultra-high-speed electronic devices and the manufacturability of semiconductor structures at the nanoscale. He is a trustee of the GWPF. He is a Fellow of the Royal Society and of the Royal Academy of Engineering.

Preface

This paper aims to advance the debate about what, if anything, to do in New Zealand about climate change, which is real. The present public debate centres on targetting a net zero emissions economy for New Zealand by 2050, but the real actions needed to achieve this have not been examined, and especially those that can be framed in terms of engineering projects.

To tackle this challenge head-on, I imagine that I have been appointed CEO of a new agency set up by the Government of New Zealand with the prime objective of delivering a net-zero emissions economy for New Zealand by 2050. It took me a few months to scope the project and to estimate the assets required to succeed. This is the result of that exercise, and the consequences that flow from the scale and timescale for meeting the target.

Executive summary

The cost to 2050 will comfortably exceed \$550 billion, a workforce comparable in size to the health sector will be required for 30 years, including a doubling of the present number of electrical engineers, and it will need about 10% of the global annual production of lithium, cobalt, neodymium and other materials. On the manpower front, New Zealand will have to rely on the domestic workforce, as I assume that every other country in the world is working towards the same target. If they were not all so working elsewhere, the value of the New Zealand specific target is moot. Without a detailed roadmap, as exemplified by the International Technology Roadmap for Semiconductors that drove the electronics revolution since 1980, the target is simply unattainable.

Introduction

Imagine we have a net-zero emissions economy in New Zealand by 2050. It follows that three very large multidisciplinary engineering projects have been completed:

- Ground transport will have been electrified.
- Heat, especially industrial heat, will have been electrified.
- The electricity sector – generation, transmission, and distribution – will have been greatly expanded to cope with the increased demand from the first two projects.

In addition, the government must have secured public buy-in for what is almost certainly going to involve much social disruption, reduction of freedom of choice, enhanced levels of demand-driven inflation, reduced capacity for government expenditure on other priorities, diminished living standards, and an economy that is much more focused and disciplined than the public have been used to.

The successful completion of these projects is necessary to meet the high-level target, but they are not sufficient, as I have not dealt explicitly with air and sea transport, nor the costs of charging points for electric vehicles and the vehicles themselves. Nor have I considered the decarbonisation and methane-related issues for the agricultural sector, including forestry, since these involve wider issues. But they will certainly have further cost, human-resources and materials implications on top of what I identify in this paper.

Present patterns of energy consumption in New Zealand

The data in Figure 1 give an indication of the energy used over the thirty years 1990–2020 for transport, heating, and electricity in New Zealand.[1] It is assumed that transport energy is constant. Residential heat, which will be variable, is small compared with industrial heat, which is assumed to be constant year-round. Taking the latest data, we see that electricity represents about 28% of the energy consumed annually. In 2050, all this energy will need to be provided by green sources. In this report I consider the implications for transport and industrial, commercial and residential heat, but (as explained above) not agriculture, forestry and fisheries, which together represent of the order of 5–7% of energy use as per Figure 1(a).

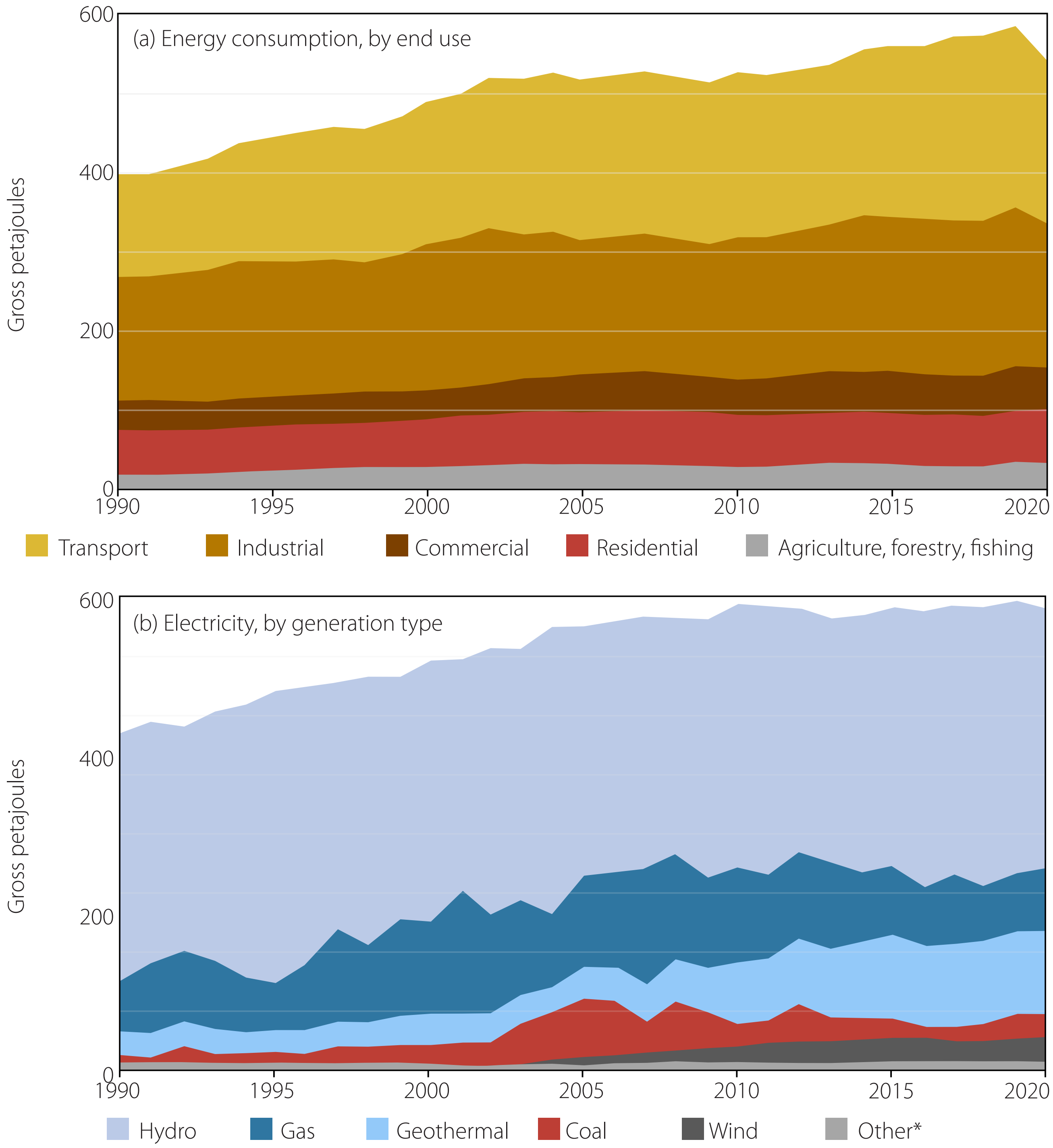

Figure 1: Energy in New Zealand since 1990

(a) Energy consumption by end use. (b) Electricity generation by type. *Including oil, waste heat, biogas, wood, solar.

Transport and heat

Current transport energy is around 200 petajoules (PJ), coming mostly from fossil fuels. This could in future be provided by approximately 70 PJ of electricity. This is because electric motors are about three times as efficient in energy terms as internal combustion engines in most vehicles today. However, some of that energy is used in shipping and aviation, where progress in electrification is far less advanced than for ground transport.

Most domestic heat in New Zealand already comes from electricity. Some industrial heat does too; for example, geothermal electricity is used at Kinleith for treating timber. However, coal burners are used by the dairy company Fonterra, and in fact, 60% of process heat is supplied using fossil fuels, mainly gas and coal. A total of 78% of New Zealand's process heat is used in industry, particularly by manufacturers, for example turning wood into pulp and paper, processing milk into powder, or sanitising equipment.[2] Another 10% is used by the commercial sector, mainly for space heating large buildings and offices. The public sector uses another 7%. For example, hospitals use steam for sterilisation and heating buildings.

To achieve Net Zero, virtually all process heat will need to be electrified. There is very limited scope for using heat pumps at scale for process heat, so industry will mostly rely on resistive heating. Heat pumps may be deployed for heat in homes and other buildings, but the poor insulation levels in New Zealand mean that major retrofits will need to be undertaken. The cost will be so high that heat pumps are unlikely to be widely used. Thus there will only be a small reduction in heat demand, perhaps only to around 200 petajoules.

The first two projects listed above will need 270 petajoules of new electricity. The existing supply is around 155 petajoules, so the third project implies an expansion of the national generation capacity and the grid by a factor of 1:2.7.[3]

Expanding the electricity sector

There are three distinct costs associated with the expansion of electricity – new generation, new transmission, and new distribution. In the absence of numbers specific to New Zealand, I will use international figures to make a first estimate of costs. A further issue is energy storage at grid scale.

Generation

I will begin my scaling up for the generation side as follows. For power generation, capacity capital costs are often expressed as overnight cost per kilowatt. Using the relevant estimated costs[4] of $4000/kW for a mix of onshore and offshore wind, $3000/kW for solar, and $8000/kW for nuclear, with a weighted average to ensure security of supply of $6000/kW, we arrive at an estimate of $60 billion for an extra 270 petajoules of electricity.[*]

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[*] Note the mixed units: 1 kW is 1 kilojoule per second, or 31 gigajoules per year.

In a dry year, New Zealand's generation falls by 15%. Our hydro storage is not sufficient to compensate for all of this shortage so some extra energy storage will be required to replace coal burning at Huntly. Additional storage will be needed to keep the lights on when there is insufficient wind or solar power. The storage is likely to be very expensive.

Nuclear power, which is reliable, safe and emissions free, will become a viable option once small modular reactors are available – in the next 10 years or so. Nuclear's major benefit is that it avoids the need for the expensive storage required to back up the intermittency of wind or solar power.

In the coming decades, and probably forever, it will be more efficient to use fossil-fuel-based electricity directly for heat and transport than through the intermediation of hydrogen. Early political direction will be required on the problem of the precise mix of new generation electricity and energy storage needed to provide a reliable supply.

Transmission

The cost of transmission assets required depends on the decisions to be made about the generation and storage issues. That is because Transpower, the grid operator, does not know what new forms of generation will be deployed, nor where, and so cannot seriously cost the transmission assets required to support them. Indeed, every other aspect of the Net-Zero project is downstream from the decisions made about how all this electricity will be generated. What we can say, however, is that today the national grid contains 11,803 km of (220-kV) high-voltage lines and 178 substations. Using a US figure[5] of about NZ$3.5 million/km for 220-kV lines, and assuming the grid expands proportionally to generation capacity, the cost will be $70 billion. The extra substations alone will cost about $300 million.[6]

Distribution

This aspect is often overlooked. We know that in parts of Auckland and Wellington, and possibly elsewhere, the infrastructure for the local distribution of electricity is already at full capacity. Historically, a house has a 60-A (ampere) fuse, the standard being set many decades ago when a 13-A stove was the most demanding appliance. In the all-electric home of the future, heat pumps can draw 58 A at start-up, while radiant hobs can draw 27 A. Meanwhile, fast (slow) chargers for electric vehicles draw 33 A (12 A), and electric showers draw 33 A. The mains fuses will therefore undoubtedly need upgrading, and the local substations will need to be greatly expanded too. In some configurations, the wiring in houses will need to be upgraded, and new transformers installed in the street to supply the extra currents. It has been estimated to cost £700 billion to carry out this work on local distribution for the UK.[7] On a pro-rata household basis, the New Zealand costs would be of order $140 billion: given the lower population density, however, the amount of new distribution will only apply to about half the population, so a reasonable estimate would be around $70 billion. Without this spending, city-dwellers would have to live with frequent power failures.

It is important that some of this work starts immediately, as the distribution systems in Auckland and Wellington are already near capacity today, and cannot cope with a substantial increase in demand.

The main electrical works needed to deliver the three initial engineering projects will cost of the order of $200 billion. However, there are further bills that will need to be paid: for a new electric vehicle fleet, the infrastructure for charging them, and the transition costs of maintaining both a fossil fuel and an EV infrastructure. These are not examined in detail here.

Grid-scale storage

The dry-year problem we have already mentioned with hydro-electricity will be augmented by the problem of how to generate electricity when the wind is not blowing and the sun isn't shining. Our society and economy are based on electricity being available at an acceptable price when and where we need it. To set the scale, pumped hydro is being considered for storage purposes. The Lake Onslow scheme will store 5–7000 GWh, enough to run New Zealand for about 7 weeks, after which we have to wait for the lake to be refilled with water, which can take years.

It remains a hard fact that fossil fuels are much more effective at storing energy than any known non-nuclear alternatives (Table 1).[8] Consider the argument that the back-up electricity supply for emergency wards in hospitals could be provided by batteries by 2025 or soon thereafter. The 100-MW, 128-MWh battery installed by Elon Musk near Adelaide in 2018 at a cost of $90 million would power the emergency wards of Wellington Regional Hospital for 24 hours on a single 80% to 20% discharge.[9] If a storm took out the transmission lines in Wellington for a week, we would need seven such batteries. The back up today is provided by diesel generators, which run if there is fuel, and cost of order $0.5 million. There is therefore a capital cost ra-

Table 1: Energy density of different fuels.

Source: MJ Kelly, 'Lessons from technology development for energy and sustainability' MRS Energy and Sustainability 2016; 3: 2–13.

Technology	Energy density
Wind turbine	0.00006
Lead-acid battery	0.15
Hydro	0.72
Wood	5.0
Petrol	50
Hydrogen	143
Nuclear fission	88,250,000
Nuclear fusion	645,000,000

tio of 180:1 per day or 1300:1 per week for battery versus diesel. This economic mismatch applies to all other suggested applications of batteries, such as using them to protect against blackouts in Wellington's Central Business District in the absence of wind and solar power.

As already noted in respect of transport, using hydrogen as an intermediary is less efficient than using fossil fuels directly. There are further issues whenever it is considered as a storage medium. For example, to gauge the role of a hydrogen economy for electrical heating, the following data[10] is useful: houses on average use 7000 kWh annually, ranging from 5870 kWh on the West Coast (where homes are heated with wood) to 8550 kWh in Canterbury (where homes are heated by electricity). If we assume all homes are heated by electricity provided by hydrogen, the storage requirements are as follows. For each house, we would to store 7000 kWh of hydrogen, which means a cube of size 10 metres, which is bigger than the house itself. In total, a cube of side 1.26 km would be needed to store hydrogen for New Zealand's 2 million homes at standard temperature and pressure. A greater volume would be needed if the hydrogen were to be used to generatate electricity. Pressurising the hydrogen reduces the volume but takes some of the energy in the process.

A similar argument applies to using hydrogen for heavy duty vehicles: a truck and trailer doing 20,000 km per year needs a huge hydrogen store: a cube of side 60 metres (at standard temperature and pressure).

Apart from the huge storage volumes, the fuel needed to make hydrogen in the first place is better used directly than through the medium of hydrogen in terms of efficiency and cost.

Improving the thermal envelope of buildings

Heat pumps are often promoted as alternatives to radiant heaters, but the idea is compromised in New Zealand because our homes have a very poor level of thermal insulation by international standards. This is because of the climate: homes at the equator or nearer the pole have better insulation to keep heat out and in respectively.

A comprehensive programme to retrofit insulation to the housing stock could be contemplated. In 2009, at my request, the UK Science Minister commissioned the retrofit of over 100 social houses.[11] The results were disappointing. For a particular set of 45 houses subject to a whole-house retrofit, at an average expenditure of NZ$170,000, the average reduction in carbon dioxide emissions was 60%, with only 3 houses getting to the target of an 80% reduction. These were all one-off projects, but even with a well-developed sector and supply chain, each house demands a precise bespoke solution, because insulation must be fitted to very high standards to achieve deep reductions in energy use. In New Zealand, houses are bigger than in the UK, and so a cost per household of considerably more than $200,000 would be needed, with the total of the order of NZ$200 billion, even allowing for a generous reduction for New Zealand's mild climate. A further NZ$100 billion would be needed for non-domestic buildings, which are bigger and more complex than individual houses.

One must be careful here to avoid double counting. If all buildings were retrofitted to the highest standard, less electricity would be needed, and if all the electricity was zero-carbon, no retrofitting would be needed. There is a complex trade-off here to be worked through. Indeed, to the extent that improving the thermal envelopes of buildings is rather more expensive than generating more electricity, as described above, a finite budget will go further if the focus is on more generation of low-cost low-carbon electricity rather than chasing down the last 30% of emissions from buildings.

Note that the three engineering projects to date will cost of the order of $250,000 per household!

Human resources

We now consider the human resource requirements to deliver the three engineering projects.

Firstly, consider the workforce required for the electrical works. The UK engineering firm Atkins estimate that a $1 billion project in this area, lasting 30 years, would require more than 15 professional engineers and 50 skilled tradespeople for the duration.[12] For the $200 billion net-zero electricity project, we will therefore need about 3500 electrical engineers and approximately 11,500 skilled people working full time for the thirty years to 2050. Larger numbers will be required in the early years of the project in the build-up phase. New Zealand currently has 3500 electrical engineers,[13] so we would need to train up the same name number again, and maintain a workforce that was more than doubled. Training professionals from school-leaving age takes 7–8 years, acknowledging that most engineering students will not be fully proficient on graduation. Workforce planning and recruitment into training therefore needs to start immediately, with directions and funding given to the universities.

Meanwhile, for retrofitting, both semiskilled and highly skilled personnel are needed. Comparing the budget of the putative retrofit sector ($10 billion per year for 30 years) with the health sector in New Zealand ($25 billion per year now) suggests a need for a workforce of the order of 100,000 people, covering areas from the design of individual projects through the materials supply chain to the actual retrofitting work on the ground.

These two projects therefore represent major perturbations to the national workforce. There are no prior examples in history to indicate that we can generate such large numbers of skilled personnel, and maintain them over 30 years from a standing start.

Bill of materials

The actual costs of the materials required are covered above. In this section I look at the quantities required. The move from fossil fuels to renewables is a transition from a fuel-intensive to a materials-intensive energy sector. Given popular concern about the environmental impact of mining, there will be significant risks of community objections as we go forward.

As an example, a 600-MW combined cycle gas turbine (CCGT) contains 300 tonnes of high-performance steel. We would need 360 5-MW wind turbines, each running at 33% efficiency, and a major storage facility to achieve the same 600 MW continuously from wind. Since the lifespan of wind turbines, at 25 years, is less than half that of CCGTs with a single life-extension refit, we would need 720 of them. The mass of the nacelle of a 5-MW wind turbine is comparable to that of a single gas turbine.[14] Furthermore, the mass of concrete in the plinth of a single CCGT is comparable to the mass of concrete for the foundations of each onshore wind turbine, and rather less than the concrete and ballast for each offshore one. A corollary of the multiplicity of turbines or solar panels is that connecting them to the grid demands more materials.

A 1.8-GW nuclear plant and turbine produce about 1000 W/kg of steel in the combined unit, compared with 2000 W/kg for a CCGT and only 2–3 W/kg from solar panels or wind turbines. These factors, of order 1000, show how much more intensive is the use of high-value materials (steels, silicon, and polymers) in renewable generation at the point of generation. This advantage for CCGTs is offset somewhat by the absence of fuel for renewables. The extraction of oil and gas only has a small impact on the Earth's surface (coming out of the grounds in pipes that are less than a meter in outside diameter), compared with the mining of the minerals required for renewables, so that Net Zero could well be regarded as environmentally unsustainable.

If New Zealand were to convert to an electric vehicle fleet overnight, the materials requirements for the batteries alone would be (pro-rated based on UK data):[15]

- 21,000 tonnes of cobalt – just under 20% of the annual global production;
- 26,000 tonnes of lithium carbonate – 7% of the world's production;
- at least 720 tonnes of neodymium and dysprosium – nearly 10% of world's production of neodymium;
- 236,000 tonnes of copper – more than 1.5% of the world's production in 2018.

If the world is to go all-electric in 30 years, we need to convert 30 New Zealands per year. We can therefore see the need for a very steep rise in the mining of these materials to meet global demand. Unregulated and child labour is already implicated in much mining of cobalt, so there are intense research efforts to replace this mineral without losing too much battery efficiency.

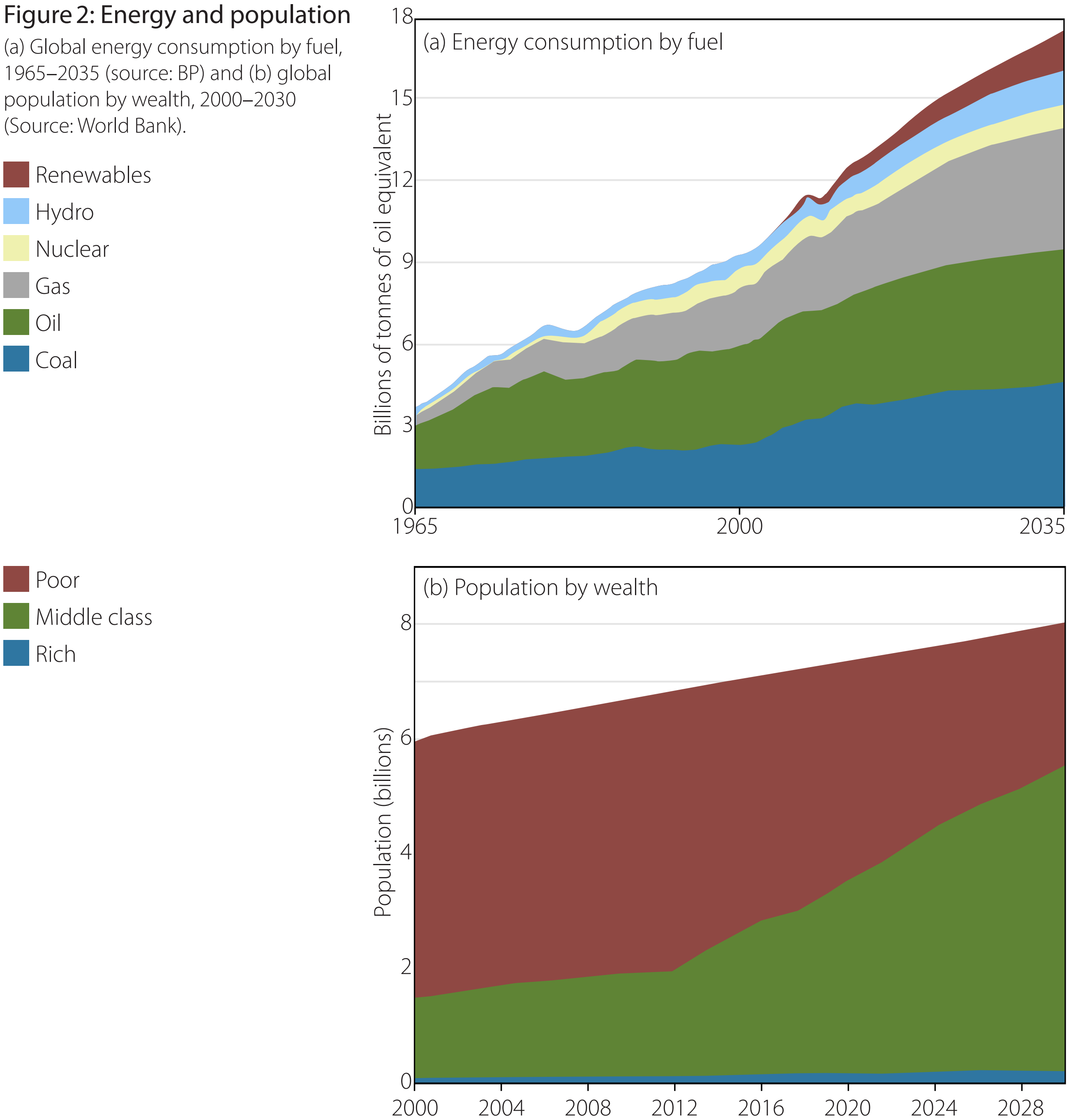
In addition, China has a near monopoly on many of these materials, and is buying up reserves in Africa, Australia, and South America to extend its control: it will be a one-nation OPEC for renewable energy generation.

The global context of NZ actions

Figure 2 shows World Bank data proving that the principal driver of the growth in energy use and carbon dioxide emissions, over the last 40 years and for the next 30 years, has been (and will be) economic development – the growth in numbers of people

Figure 2: Energy and population

(a) Global energy consumption by fuel, 1965–2035 (source: BP) and (b) global population by wealth, 2000–2030 (Source: World Bank).



moving out of poverty into higher-income categories. Consider a person who leaves an urban slum or rural hovel to dwell in a high-rise city apartment, with electricity for heating, lighting and communication. If they use between three and four times the amount of energy as before, then the data on energy consumption between 1980 and 2035 (even extrapolated to 2050) can be explained *quantitatively*.

Energy consumption per person in developed countries has been steady or on a slightly downward slope over recent decades, as energy efficiency gains have oustripped increased usage. All the increases in carbon dioxide emissions have come from India, Asia, and Africa.

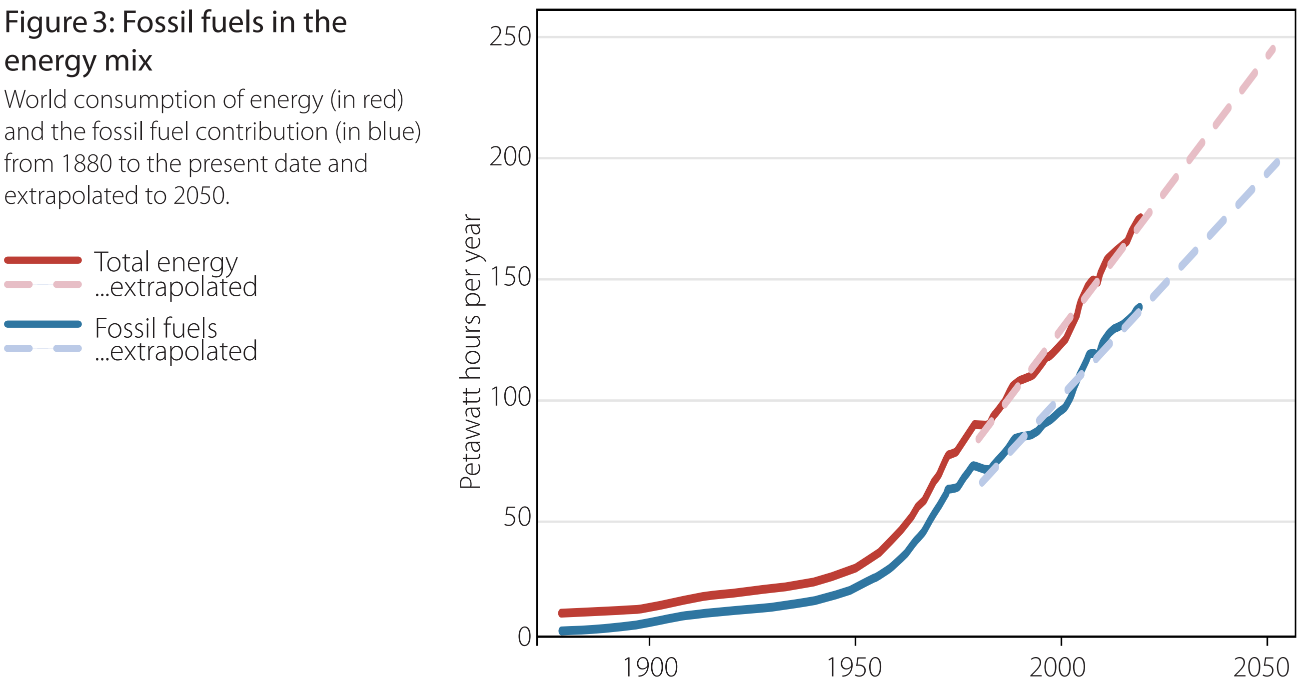
Note, furthermore, that the first and second UN Sustainable Development Goals are the elimination of world hunger and poverty. Action on the climate is the thirteenth. Although the goals are not ranked by importance, it is unlikely, on basic humanitarian grounds, that climate action would be given much greater emphasis.

One can see in Figure 3 the dominating role that fossil fuels have had in energising the world economy since the 19th century. Since 1980, all the efforts on renewables have contributed to a slight divergence. The share of fossil fuels in energy mix, which has been around 85% for a century, has now fallen to nearer 82%. Extrapolation out to 2050 indicates a 79% contribution in 2050: there is no sign of a rapid divergence and a zeroing of the fossil fuel share in the next 30 years.

These and many other developments, such as the quadrupling of the SUV global market in the last decade, all show the world going away from the Net Zero target. The Glasgow climate conference (COP26) promised a minor dent in this trend, but no

Figure 3: Fossil fuels in the energy mix

World consumption of energy (in red) and the fossil fuel contribution (in blue) from 1880 to the present date and extrapolated to 2050.



major downturn in emissions, and even these commitments are being sidelined as a result of the present energy shortages.

In this section, I have made no allowances for possible radical technological breakthroughs in the energy sector. These might relieve the situation on the timescale of decades, but hoped-for incremental improvements, say in battery technology, might be slower than anticipated, as the intrinsic limits of materials' properties are approached. Any such delays would worsen the situation.

In addition, civil infrastructure is much more materials- and human-resources-intensive than electrical infrastructure. The timescale of the Transmission Gully motorway project, which took 10 years from consent to completion, has to be borne in mind when estimating how long such major infrastructure changes might take.

Public acceptance

It is clear that the public has no idea of the scale of the changes that would be required to transition to a net-zero economy in 30 years' time. This is not only a matter of the costs, the human resources, and materials, but also the disturbance to everyday lifestyles that will result. Opinion polls indicate that most people are only willing to pay modest sums to decarbonise the economy. No poll has tested their willingness to meet the level of costs implied by the analysis above, well over $250,000 per household. That willingness must surely be particularly doubtful if the public also become aware that there will be no measurable difference in the future climate as a result. To make a difference, one would need to help finance similar projects in places such as India, south Asia, the Middle East, and Africa. If one assumes that the EU, North America, Australasia, and Japan are to underwrite the rest of the world's activities, then the costs to their citizens will rise by a factor of five. This would take the cost to each New Zealand household to more than $1 million. In practical terms, this takes us into fantasy land.

By all commonly understood value-for-money exercises, climate mitigation simply does not add up. For homes, the $250,000 per household would be recouped over more than 50 years at today's cost of energy, far longer than any sensible investor would tolerate. Clearly this cost cannot be transferred to energy consumers. Very few households could afford it. The impact of even partial cost recovery would be hugely regressive, pushing middle-income people into poverty. Massive Government funding and commensurate tax increases would be required, with obvious impacts on other budget priorities. It is not clear how public acceptance for these projects can be achieved on the timescales required.

Funding for adaptation to an actual changing climate is an easier ask. As an example, extensive flooding in the 1953 storms in the East of England triggered actuarial calculations. When should a barrier across the Thames be constructed such that in its design lifetime it will have prevented insurance claims against flooding in London equal to the cost of the barrier itself? The answer was 'in the 1980s'.

In developed countries with seismic activity, such as New Zealand, it is easy to set aside and invest multiple billions of dollars to cover future earthquakes, but that is because most people know they could be claimants during their lifetimes. The slow-burning climate change could attract the same investment vehicles to allow for expenditure on adaptation as and when it proves necessary, based on appropriate actuarial calculations. However, most alarming climate forecasts are based on the so-called RCP8.5 future emissions scenario, which has been widely discredited as being unrealistic: this implies that climate change will inevitably be slower. This strengthens the case for adaptation as needed, rather than mitigation against a longer-term possibility.

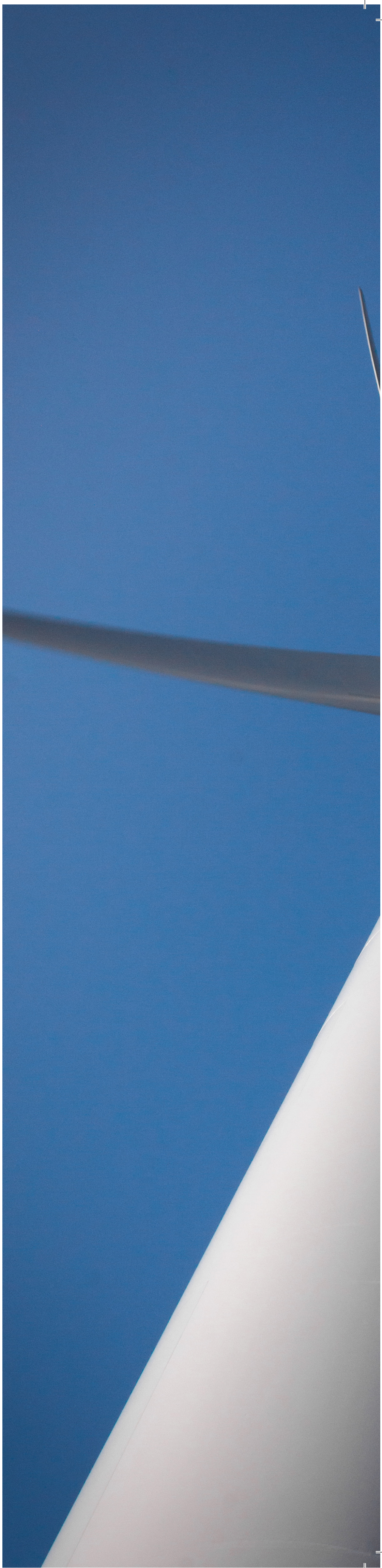
Spend profile and secured finance

Most of the preceding analysis assumes a constant 30-year project spend. In practice, the spend will start from near zero and ramp up. If a 40-year insulation retrofit roll-out had started in 2010, we would have spent around \$50 billion, or 15–20% of the \$300 billion total, by now. How would we have funded and delivered that project? In practice, we have spent only of order of \$3 billion, or 1% of the total so far. Each year of delay adds more to what must be achieved in the later decades, necessitating even greater flows of finance, human resources, and materials in future. The training of a skilled workforce and building up the supply chain must precede mass roll-out in all sectors. The expansion of the grid must precede the mass uptake of electric heating and transport: having the cars and heat-pumps without the green electricity is unworkable.

A project on this scale will need bespoke financing at the national level, as it is beyond the scope even of the richest companies in the world today. Even international money markets would struggle if all the world should pursue the Net Zero target. Completely new economic thinking would be needed.

A partial list of factors not yet considered

I have given no attention to agriculture, and especially methane emissions, nor forestry, a sector which can reduce carbon dioxide emissions, at least while trees are growing. Similarly, I have not considered aviation or shipping, although these are an essential part of the New Zealand economy, not least for trading. Aviation fuel will be with us through and beyond 2050, and evolution of electric shipping is very slow beyond commuter ferries in city harbours. The global economy depends very much on both these forms of transport, and any severe curtailment will be accompanied by falling standards of living.



I have not included the extra costs of simultaneously running the two new infrastructure systems required to support fuelling internal combustion engines and recharging electric car batteries. I have not considered the practical choices associated with where and how the extra electricity generation should occur, nor have I factored in the costs of any forms of electricity storage (which are very high, as noted earlier). These issues will need an early resolution, because many of the desired outcomes depend on the new infrastructure being in place. I have not examined the ever-growing costs of balancing the grid, costs which grow dramatically as more intermittent sources of electricity that are unable to help manage frequency or voltage become more prevalent.

A major change in peoples' lifestyles, with reductions in travel, consumption, and food variety, could make a dent in the numbers above (but would not noticeably reduce the scale of the engineering projects required). However, this would be a challenge in a democracy, particularly when the developing world, which has no alternative, continues to burn fossil fuels. One may quibble about individual estimates I have made above, but this will not reduce the final numbers by a factor of 10 or 100 to make the exercise more palatable.

A roadmap for New Zealand

The success of the IT revolution over the last 40 years is in no small part due to the existence of the International Technology Road Map for Semiconductors (ITRS). Engineers from every part of the electronic sector, and all parts of the world, gathered every two years to thrash out in great detail what needs to be coming out of the laboratory into development, and out of development into production, to keep Moore's Law of transistor miniaturisation on track, and with it the increase in computing power. Every player in the industry knows that the others are investing and working day-by-day to the same agreed objective. The contrast between ITRS and the Conference of the Parties to the climate change agenda is extreme. Meeting the 2050 Net-Zero emissions target is much more complex than information technology, and without a very detailed roadmap, agreed by all players, and the technology and resources to achieve it, the project is more likely than not to fail.

A roadmap for climate adaptation is much simpler to contemplate. For example, there is a 68-km cycle route planned at the water's edge round Wellington Harbour, from Red Rocks to Pencarrow Head. A concrete wall one metre thick and five metres high along that route would cost $300 million, and would protect Wellington against rising seas for centuries. Moreover, there is no need to build it all at once. Instead, smaller walls can be built first, concentrating on those few parts where storm surges are already an issue.

Summary

Achieving Net Zero by 2050 will cost more than \$500 billion, in today's dollars. A dedicated and skilled workforce, about half the size of the health sector, is required, and must be recruited and trained as a matter of urgency. This workforce will have to come from local human resources, given that the same skills will be in demand in every other country seeking to meet the target. We may need controls to prevent skilled workers from being 'poached' by other countries.

The quantities of key strategic materials demanded are many times the supply rates that prevail today. Logistics problems and inflationary pressures will inevitably result.

The practical alternative

We are certain to have major economic and societal disruption associated with delivering the net-zero economy by 2050. However, there is an important consideration, namely the demographic transition that started 70 years ago. Across the globe, the average family size has halved from 5 children in 1960 to 2.5 children now, and the figure is continuing to fall. In developed countries, with universal primary education and more people living in cities than the countryside, the figure, at 1.2–1.7, is well below 2. As a result, indigenous populations are in absolute decline, as it takes 2.1 children per family to maintain a population. Stably governed developing countries, such as Bangladesh and Lesotho, are already down to 2.5. The Chinese population will peak in the 2030s and the world population in the 2060s. A century from now, when we need copper, maybe we will not mine it, but strip it from abandoned cities.

My analysis requires us all to ask of the climate science community how bad the climate will (as opposed to might) become, and when. The solutions discussed here seem far worse for society than the problem to be solved. Moreover, as already noted, most alarming analyses of the future climate are based on an emissions scenario (RCP8.5) that has long since been discredited. Candour and humility at this point would assist those making the case for funding both climate mitigation and adaptation, which will only be carried out when it becomes necessary. In the parlance of the Second World War, 'Is this journey really necessary?'

Personal view

I hope this report gives the bare facts about what is implied by committing New Zealand to a net-zero emissions economy for 2050. If I am correct, the goal is unattainable and even attempting it will come at very great cost. We need, right now, a meaningful public conversation about the practical implications of trying to achieve Net Zero within 28 years. We need the Royal Society of New Zealand, Engineering New Zealand, economists, environmental scientists and public policy experts to participate in a serious, open-minded discussion of the engineering, financial and economic realities. The possibility of a renewed focus on adaptation, combined with a realistic emissions pathway, should at least be on the table for comparative analysis.

I think that the hard facts will put a stop to mitigation and lead to a focus on adaptation. Mankind has adapted to the climate over recent millennia and is better equipped than ever to do so in the coming decades. The Dutch have been showing us for centuries how to deal with sea-level rise. Climate adaptation in the here and now is a much easier sell to the New Zealand citizenry than mitigation.

There is a very strong case to repeal the net-zero emissions legislation, replacing it with achievable goals and realistic timescales. The scope for malinvestment is great and the sums are enormous.

Postscript

An important book, by an internationally renowned scholar of energy, food and materials systems, has just been published. *How the World Really Works: A Scientist's Guide to Our Past, Present and Future*,[16] by Vaclav Smil, makes many of the same points set out above. In particular, the key sentence from the introduction is this:

> The gap between wishful thinking and reality is vast, but in a democratic society no contest of ideas or proposals can proceed in rational ways without all sides sharing at least a modicum of relevant information about the real world, rather than trotting out their biases and advancing claims disconnected from physical possibilities.

Notes

1. Energy in New Zealand 2021 (mbie.govt.nz).
2. Process heat in New Zealand, Ministry of Business, Innovation & Employment (mbie.govt.nz).
3. (155 + 270)/155 = 2.7.
4. Cost of electricity by source, Wikipedia.

- gas/oil combined cycle power plant – $1000/kW (2019)
- combustion turbine – $710/kW (2020)
- onshore wind – $1600/kW (2019)
- offshore wind – $6500/kW (2019)
- solar PV (fixed) – $1060/kW (utility), $1800/kW (2019)
- solar PV (tracking) – $1130/kW (utility), $2000/kW (2019)
- battery storage power – $1380/kW (2020)
- conventional hydropower – $2752/kW (2020)
- geothermal – $2800/kW (2019)
- coal (with SO_2 and NOx controls) – $3500–3800/kW
- advanced nuclear – $6000/kW (2019)
- fuel cells – $7200/kW (2019)

5. https://nocapx2020.info/wp-content/uploads/2019/07/Transmission-Cost-Estimation-Guide-for-MTEP-2019337433.pdf.
6. Transpower-Substation-Management-Systems-Business-Case-27-June-2014.PDF (comcom.govt.nz).
7. https://www.thegwpf.org/content/uploads/2020/07/Travers-Net-Zero-Distribution-Grid-Replacement.pdf.
8. https://www.thegwpf.org/content/uploads/2019/11/KellyWeb.pdf.
9. I have the precise numbers for Addenbrookes Hospital in Cambridge, which is comparable in size to Wellington General.
10. How much electricity do NZ homes use in summer compared to winter? (nzcompare.com).
11. Rajat Gupta, Matt Gregg, Stephen Passmore, and Geoffrey Stevens. 'Intent and outcomes from the Retrofit for the Future programme: key lessons', *Building Research & Information*, 43(4); 435–451, 2015. See https://www.tandfonline.com/doi/pdf/10.1080/09613218.2015.1024042.
12. Private communication from an Atkins director.
13. https://www.careers.govt.nz/jobs-database/engineering/engineering/electrical-engineer.
14. Development of 5-MW Offshore Wind Turbine and 2-MW Floating Offshore Wind Turbine Technology (hitachi.com).
15. https://www.nhm.ac.uk/discover/news/2019/june/we-need-more-metals-and-elements-reach-uks-greenhouse-goals.html.
16. 2022, Viking, Penguin Random House.

About the Global Warming Policy Foundation

People are naturally concerned about the environment, and want to see policies that enhance human wellbeing and protect the environment; policies that don't hurt, but help.

The Global Warming Policy Foundation (GWPF) is committed to providing a platform for educational research and informed debates on these important issues.

In order to make progress and advance effective policy assessments, it is essential to cultivate a culture of open debate, tolerance and learning.

Our aim is to raise standards in learning and understanding through rigorous research and analysis, to help inform a balanced debate amongst the interested public and decision-makers.

We aim to create an educational platform on which common ground can be established, helping to overcome polarisation and partisanship. We aim to promote a culture of debate, respect, and a hunger for knowledge.

GWPF NOTES

For further information about the Global Warming Policy Foundation, please visit our website at www.thegwpf.org.
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