Sustainable Energy – without the hot air - A New Zealand Perspective.

by Phil Scadden and Oliver Bruce

This contribution to the discussion about renewable energy options for New Zealand follows the approach of David MacKay, a Cambridge physics professor and Chief Scientific Advisor to the UK Department of Energy and Climate Change. In his 2009 book (republished Sept 2011) "Sustainable Energy – without all the hot air" (available for free download at http://www.withouthotair.com/), MacKay uses basic physics to look at the questions associated with sustainable energy, calculating what is physically possible before assessing what is economically achievable. As an advocate of sustainable energy, he describes himself as "pro-arithmetic" rather than a campaigner for one type of energy production over another, which is surely what informed debate needs. His motivation is two-fold. Firstly, rising CO_2 emissions from fossil fuel threaten the world with rapid climate change. Secondly, our energy security is threatened by diminishing oil reserves which means production cannot keep up with demand. The majority of MacKay's calculations are done for the UK. Phil was interested to see what the comparable figures for New Zealand would look like given our different level of renewable energy use, availability of public transport, population density, and age and types of houses. So, in 2009 he drafted the original document. Oliver came across this paper after reading McKay's book and how such analysis might apply to New Zealand. He wanted to know the latest figures, so has provided the updated calculations for 2012.

In this document, we have focused on two questions.

1. ***Can New Zealand maintain its current per capita energy consumption without fossil fuels and, in particular, can we live on renewable energy sources alone?***

2. ***How can we achieve a BIG reduction in our personal and national energy consumption, in order to reduce our power requirements?***

Our main data resource is the Energy Data File, available from the Ministry of Economic Development, (http://tinyurl.com/deraff). The most recent data is up to the end of 2011. Important supplementary data came from various Energy Efficiency and Conservation Authority (EECA) reports (http://tinyurl.com/ydtzb5v) . (In future, web references will just be the tinyURL code. Eg the EECA library will be [ydtzb5v]). In addition to the Energy Data File, NIWA undertook a project called Energyscape in 2007/08 that mapped New Zealands energy options. Some of their findings have also been included [d82wl49]. Finally, the government has also studied the issue in some detail with numerous technical reports available from the Electricity Authority. [9cg5fp7]

Following MacKay's example we will present all energy data in kWh/day/person, energy consumption units that most of us are familiar with from our monthly electricity invoices. To give you an understanding of the numbers, one 40W lightbulb consumes 40W per hour, or ~1000W hours (1kWh) a day. Most toasters are rated to 1kW, so running one of these for an hour will take 1kWh of power. A petrol car driving 100km will use, on average, 7 to 9 litres of petrol, which is the equivalent of 70-90 kWh of energy (one litre contains ~10 kWh). If interested, read McKay's chapter on his reasoning and methodology here: [8z7lwjg]

Energy reporting for New Zealand is complicated by the questions of gross versus net, and by how and where energy transmission and transformation costs are accounted for. Again, we will follow MacKay's book usage as far as possible and do the accounting in a way that is relevant to the questions being asked. Are our numbers to be trusted? Well no – we make mistakes. If something doesn't seem right, then please go back to the spreadsheet that we have used to make all calculations (found here: 9g5oupc), and email errors to pc.scadden@ihug.co.nz or oliver.bruce@gmail.com.

1. Can NZ live with renewable energy only?

New Zealand consumer energy use (electricity and fuels) in 2011 was **88 kWh/d/p** from all sources, and represents a drop of approximately 5kWh/d/p since 2007. Some notes are required about assumptions used in deriving this figure. The "official figure" is 138kWh/d/p but this includes energy in coal and crude oil that is immediately exported, as well as all the energy losses involved in converting fossil fuel to electricity. However, these factors distort personal consumption figures and any consideration of how to replace one energy source with another.

Unfortunately, neither figure (i.e. 88 or 138) is a real indication of our total energy use, because both exclude "embodied energy" in imports such as cars and electronics, and exports in things like aluminium. The numbers also do not account fully for fuel we use in overseas air travel since only fuel sourced here is counted.

Currently 50% of the 88kWh/d/p is from oil alone, and only 32kWh/d/p is from renewable energy sources. While this represents a growth of ~3 kWh/d/p of renewables since 2007 (mainly due to wind and geothermal projects), it still leaves a big gap for improvement..The challenge is could we reduce our energy usage so as to live either on existing or expanded renewable sources alone? Costa Rica, North Korea and Indonesia manage to survive on around 30kWh/d/p from all sources but could we? Presently no developed country is even close.

Conclusion: To maintain existing energy consumption levels and reduce our dependency on fossil fuels we will have to say yes to new renewable energy development.

There is no magical efficiency fairy that can allow us to maintain anything like our current lifestyle without the development of new renewable energy sources. For example we need to find another 6kWh/d/p of renewable generation just to generate our current electricity without using coal or gas.

Fossil fuel use raises major issues with respect to impact on climate and sustainability of supply. MacKay builds a case for the western world aiming to reduce fossil fuel consumption to effectively zero by 2050, putting aside the question of whether this will be too late to avoid catastrophic consequences for many people. For New Zealand to achieve this goal we need to find another 56kWh/d/p from renewable sources to maintain our current lifestyle.

However, there is one permissible use of coal which by itself would have low impact on atmospheric CO_2. This is steel production, because we do not have an alternative technology for steel making - which is essential in many components widely used in housing construction etc. If we must have steel and cannot afford the emissions then CO_2 capture must be achieved. If 1.25kWh/d/p of coal is used (current consumption), this reduces our energy production gap to ~55kWh/d/p.

The temptation at this point is to selectively extinguish major industrial energy users, thereby freeing up existing renewable energy. For example, why not close the aluminium smelter? The Tiwai smelter uses 3kWh/d/p producing aluminium for export, and closing this would reduce our gap to 52kWh/d/p [9lhp5ok]. However, aluminium is a very useful metal with many redeeming qualities, and can be easily recycled. Reducing our demand for aluminium would be useful but merely exporting the energy demand elsewhere is not. As we shall see, New Zealand is relatively well off for renewable energy and it could be easily argued that here is actually a good place to smelt aluminium.

So what is the potential for renewable energy in New Zealand?

Hydroelectric

Currently, ~15kWh/d/p of energy comes from hydroelectric generation. How much more is feasible? For the United Kingdom, MacKay simply does back-of-the-envelope calculations, but because of widespread hydro-electrical use in New Zealand, there are reports that allow us to make a more complete assessment of hydroelectric potential. [8k8vf25] and [9nvw27h]. Firstly, I discount any scheme that would be in a National park, or protected by a strong Water Conservation Order (e.g. Motu), or extremely remote. Some 34 schemes of >20MW capacity have already been identified as economically and technically feasible (e.g. Mokihinui River). These deliver a potential of 10kWh/d/p. on top of the 15.4kWh/d/p already commissioned. 26% of that is from North Bank Tunnel project in the Lower Waitaki and a further 22% comes from four possible schemes on the Clutha River.

A further 289 sites have been investigated for schemes of >0.5MW and <20MW. Together these smaller schemes have a potential for 10.5kWh/d/p, though only 3kWh/d/p is estimated for schemes that are economic at today's prices.

What about micro-hydro? The potential for such schemes isn't easy to estimate but an EECA report [no longer available, but authored by Ralph Sims in 2006 for EECA, and entitled: "Fact sheet 6: Small hydro. *Energy Efficiency and Conservation Authority Renewable Energy Fact Sheet*"] estimated this at about 600-700MW which would provide about 3kWh/d/p, at an assumed average of 50% peak flow. With an electricity cost of $0.15 -0.30/kWh, these are attractive options for off-grid users.

In summary, a maximum realistic potential for a range of hydro options is around 23kWh/d/p beyond existing capacity. However, we must recognise that there are significant economic, environmental and social costs to realising hydro potential.

MacKay also makes a good case for using hydro schemes to balance variability in the wind and in demand.

Conclusion: To achieve energy goals based on renewables we cannot ignore hydro-potential, especially on rivers already committed to hydro-energy production.

Geothermal

Unlike the UK, New Zealand has significant geothermal resources which currently contribute to national energy requirements. Geothermal energy has the advantage of being always available at full capacity, and unaffected by weather. Currently about 5.2kWh/d/p is available (3.6kWh/d/p of electricity is produced plus 1.6kWh/d/p in direct heating) but it is estimated that there is potential for a total of 12kWh/d/p at an admittedly higher price than gas generated electricity [dbpz7n]. Environmental and regulatory constraints further limit development. The Electricity Authority foresees generation rising by a further 4.4kWh/d/p by 2025 [9v5c9my] but little growth beyond that. Geothermal energy is low quality, producing lots of hot water for disposal. Ideally, better use of this hot water in co-located industry would improve overall efficiency.

Wind

New Zealand has significant wind resources with much of the country having average wind speeds in excess of 6m/s. Even with the amount of development since the last report in 2009, we've only added around 0.64 kWh/d/p. Another 1000 turbines (around 2 times the existing capacity) could deliver 4kWh/d/p while a reasonable upper limit (avoiding national parks, settlements, structures, waterways, steep slopes, low wind areas and assuming 50% willingness by landowners) has been calculated at 83kWh/d/p [cntnmby], with 32kWh/d/p available at competitive pricing. 33kWh/d/p would see windmills on 0.6% of total NZ land area, that is, if clustered, an area the size of Stewart Island. Offshore wind hasn't been studied seriously because it is twice the price of onshore wind, and thus will not be a viable option in the foreseeable future. Furthermore, most of New Zealand does not have wide shallow sea areas like the North Sea. This restricts opportunities, as wind power gets very expensive in deep water. An approximate estimate of offshore contributions based on shallow water extent might put the potential at 40kWh/d/p.

High altitude wind captured using kites is another bet, but we've yet to find a case study of this resource for New Zealand, and the technology for harnessing it is still in its infancy. We'll assume a capacity of 0 kWh/d/p until proven otherwise.

Summary: For these first 3 sources we have a total realistic extra potential generation of 59.4kWh/d/p (hydro 23, geothermal 4.4, and wind 32kWh/d/p), without considering offshore wind. So, if we don't mind parts of the country covered with windmills, multiple new hydro schemes, including all those proposed for the Clutha and Waitaki Rivers, and new geothermal schemes, we can readily get more than our required 57kWh/d/p from hydro, geothermal and wind alone. We don't have to say yes to every wind and hydro proposal but we have to say yes to a great many of them.

And if we want power to be affordable for everyone, we have to say yes to proposals in places where it is cost-effective to generate power.

The other important point to make here is that much of the energy we'll be generating will be in different forms to those we will be replacing – ie. we'll be generating a lot more electricity, but moving away from energy in liquid fuels. Its worth noting that even if we manage to find a significant resource of oil in our offshore drilling efforts, this will be sold on the international market and won't change the long term requirement of having to transition towards renewable energy sources.

Aside from these options, there are other possible sources of power that will be become more important over time. Lets have a look at them.

Solar

Our lower latitude means that New Zealand's solar potential is certainly rather better than that of the UK and the current world leaders Germany. A roof inclined at the optimal angle in NZ gets on average 181W/m^2 in Northland, 178 in Auckland, 195 in central Otago, 185 in Canterbury. (This is based on averaging all available NIWA hourly radiation data at suitable measurement sites). This is impressive compared to the UK average of 110W/m^2 and 130W/m^2 in Germany.

There are 4 ways to harness solar energy:

1) Solar hot water – panels that directly heat water.
2) Photovoltaic (PV) – panels that convert the sun's energy directly to electricity.
3) Concentrated Solar Power (CSP): Actually a range of technologies that use reflectors to concentrate solar energy either into heat engines or onto very high efficiency PV.
4) Biofuel – photosynthesis; this is considered separately.

Installing 10m^2 of north-facing, solar hot water heating panels could deliver 8kWh/d/p of hot water per person per household (average household being 2.6 people). While this amount of energy is more than we require, sadly we currently are unable to store it for colder, gloomy winter days. Photovoltaic PV panels on 20m^2/p of north-facing roof (3kW system) would deliver 4kWh/d/p per household, which is more than enough to cover the baseload energy use of a NZ house during sunshine hours, and has the benefit of being able to feed extra power generated into the grid for use elsewhere.

What about having a solar farm instead of using everyone's house? Let's consider, for example, covering all of Central Otago with concentrating solar power station installations with efficiencies of 15W/m^2. We could halve the area to allow for skifields, dwellings, shaded slopes, mountain tops, etc. This gives us a huge 330kWh/d/p! However, the environmental and fiscal costs would also be huge, and probably unacceptable. If we confine these solar farms to an area the size of the Maniototo (40,000 hectares, which is a block 20km x 20km, OR for you North Islanders, is roughly equivalent to the size of the Auckland urban area) we could still provide 30kWh/d/p if completely covered. While such a scheme would provoke outrage, it should be pointed out that these concentrating solar farms deliver 5-8 times as much power per square meter as wind, so the overall impact footprint on the New Zealand landscape would be a lot lower. The cost is currently 2-3 times hydro, geothermal and wind but is likely to come down in the near-future. Further, the price of PV panels is now about 2/5ths of what it was in 2009 and keeps dropping.

On an individual house basis, installing, say, 5kWh/d/p of solar hot water heating makes good economic sense especially if you use a lot of hot water (or have teenagers!). Larger scale investments will have to wait for relative costs to improve, but a potential for 9kWh/d/p of house-based PV plus 34kWh/d/p of large scale solar production for a total of 48kWh/d/p seems reasonable.

Conclusion: Solar has huge potential and is the way of the future.

Biofuels

Energy problems are just one of the significant challenges facing our civilization so we are reluctant to consider options that affect food production or contribute further to soil degradation. However, as we transition away from liquid fuel-based transportation, biofuels could play a role in keeping us mobile.
We estimate that we need at least 9kWh/d/p of diesel for agricultural and heavy trucks. The best temperate crop-to-delivered-diesel is estimated by MacKay to provide $0.5W/m^2$. Therefore we would need 223800ha or 21% of all arable land to supply the required diesel.

There are extravagant claims being made for algal biofuel. Yields of 4.6 to $18.4L/m^2$ ($5\text{-}21W/m^2$) have been suggested but the higher figures are really only obtainable in CO_2-enriched water with complete control of temperature, light, and nutrients. Achieving these yields on an industrial scale will be a challenge. Since 2009, the sole commercial scale algal biofuel plant that has come online (based in New Mexico, USA) only produces around 100 barrels of oil a day, not even a drop in the ocean of the 150,000 we consume daily in New Zealand. Furthermore, where is the CO_2 to come from? Using CO_2 from thermal power stations to generate biofuel is NOT CO_2 sequestration – the CO_2 still ends up in the air when the diesel is used. So what if only CO_2 emissions from steel production are used? Glenbrook uses 800,000 tonnes of coal pa, so provided you can find 20,000ha of suitable agricultural land nearby, then this will supply 6kWh/d/p of algal diesel for around ⅛ of the equivalent area for fuel crops.

Finally, let's consider New Zealand's total biofuel potential. MacKay includes the solar component present in food when adding up energy costs, and also makes a calculation for biofuel production potential for the whole of UK. What potential biofuel production could be obtained in NZ? According to MAF [cewg8p], NZ has 14.7 million ha in production for either food or plantation forest (cf total NZ land area of 27 million ha). Converting that to biofuel at a rate of $0.5W/m^2$, gives a massive 373 kWh/d/p. Admittedly getting $0.5W/m^2$ off hill country land might be difficult but even using just our arable land (~1.5million ha) would still yield 43kWh/d/p (enough to power our car fleet as we shall see NIWA has worked on this issue as part of its BioEnergy Options for NZ pathways project [dyqotee], and determined that 'energy forestry' could produce all our liquid fuel and heating needs, but that it would take 3.2 million ha. Obviously, this a lot of land. Their analysis shows that much of the afforestation could be undertaken on marginal hill country that would minimise the impact on food production (and provide other positive benefits), but that it would only be economic at a large scale if the price of oil goes above $200. That said, all forestry residues from current production would sustain 10% of our energy requirements, meaning that it could be a piece of the energy supply puzzle. It's worth remembering that NZ is not just a net exporter of energy, we are a net exporter of renewable energy via our food. We would argue that there are better uses for our land than growing fuel for transport.

Conclusion: Biofuels are feasible at the expense of considerable agricultural intensification. Algal entrepreneurs with a scalable design can send us their investor prospectus!

Marine

The marine environment offers several possible renewable energy sources, notably wave and tidal energy.

Wave energy systems have been studied by the Electricity Authority, and data here comes from their report [yeqtogu]. Feasible wave energy plants need wave energy greater than 20kW/m "close" (say 6km) to coast. New Zealand has 2000+ km of coast-line fulfilling these parameters, mostly on the west coast. Wave derived energies in the far south can be 60 to 80kW/m, which is impressive. That is approximately 86kWh/d/p for a 50% efficient wave generator covering half our available coastline. However, a reality check indicates that no such mechanism exists (so far wave generators have been built for survivability rather than efficiency) and many factors would constrain where wave generators could be built. A fairly detailed analysis based on currently available technology has identified sites offering perhaps 2kWh/d/p and a maximum potential for perhaps 27kWh/d/p. While a number of prototype and early commercial plants have been deployed worldwide since 2009, this realistically still is best be described as an emerging technology with very substantial environmental and economic barriers to deployment.

What about tides, especially those huge currents going through Cook Strait? New Zealand has a limited tidal range so tidal pools and tidal lagoons have limited potential despite the technology's very attractive features. Studies have identified sites in Cook Strait, Stewart Island and Cape Reinga which with existing technology might yield 0.4kWh/d/p. The Kaipara Harbor Tidal Scheme was approved in 2009 and will yield approximately 1.75 kWh/d/p of tidal based power when completed (according to the project developer Crest Energy) [8cugk6t] An alternative study [9bm2evc] suggests there could be 86kWh/d/p extractable from Cook Strait, but this relies on stackable turbine technology that doesn't exist yet and is a massive engineering challenge. A more realistic take on the 10 year potential for a row of turbines for around 8.6 kWh/d/p. The wide range in estimates emphasises how little is so far known about this technology.

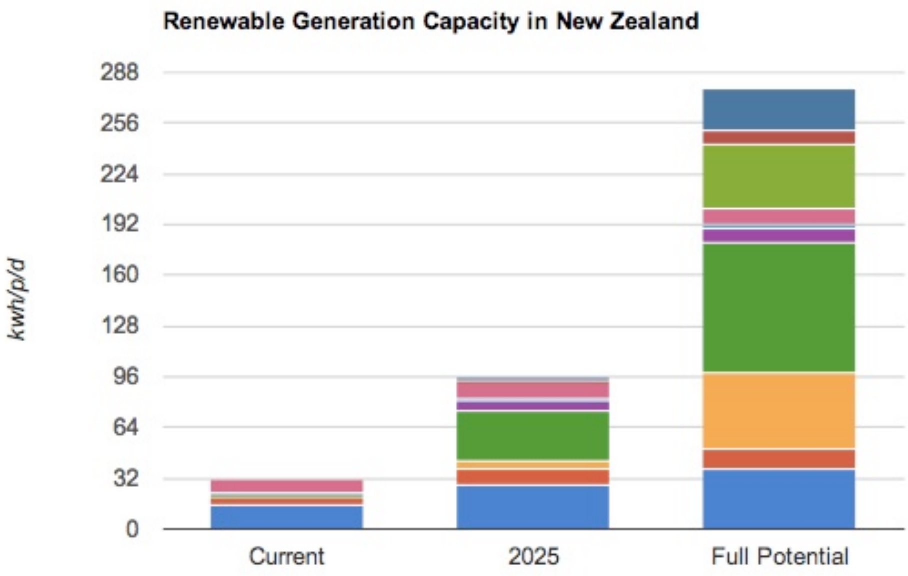
Waste Incineration and Biogas

Currently energy from biogas supplies 0.5kWh/d/p, and there is obvious scope for increasing this with increasing landfill. At this stage a potential of 1kWh/d/p seems realistic. A novel waste use is wood-waste for domestic heating via pellet burners. There would appear to be a capacity for 2-3kWh/d/p.

Summary of Renewable Generation Options

So where does this leave us for increased generation potential among renewable options? The affordable, mature technologies are hydro, geothermal, wind, waste gas, solar heating and biofuel. Large-scale solar and marine technologies are really promising options for the future but cannot be realistically considered now.

Fig.1 summarises the current and potential future amount of energy generated in NZ from the various renewable sources discussed above. The numbers used are conservative, allocating only relatively small areas to solar in the distant future. New Zealand is energy-rich but every option using renewable sources will have its own problems.



	Current	2025	Full Potential
Hydro	15	28	38
Geothermal	5	9.6	12
Solar (both PV and Thermal)	0	5	48
Onshore Wind	1	32	83
Biofuels	0	6	9
Biogas	1	1	2
Wood	10	10	10
Offshore Wind	0	0	40
Tide	0	1.8	9
Wave	0	2	27

Notes:

Current consumer energy use is 88kWh/d/p, of which 32 is from renewable sources. 50% of energy use is from petroleum.

These numbers are for current population (4.4 million). If the population grows to 5 million by 2050 as projected, then the numbers should be scaled back by 9/10.

The estimate for biofuel is based on minimal encroachment onto food producing land. Using all arable land for biofuel instead would deliver 43kWh/d/p.

Fig.1 NZ Renewable Energy Resource

And finally a word about Nuclear Energy

Nuclear energy is not a renewable resource but MacKay argues that it is possibly a sustainable energy source, and certainly it could be an alternative to lots of windmills and dams. The issues associated with nuclear energy are dealt with at length in MacKay's book and don't need further repetition here. For a New Zealand perspective, I would note that we don't have any commercial uranium deposits, we are prone to earthquakes and tsunamis with similar risks to Fukushima and that commercial technologies for truly sustainable nuclear energy production are still in the future. For the moment, New Zealand has other renewable options.

2. How can we achieve a BIG reduction in our personal and national energy consumption?

If we don't like the environmental and other consequences of the generation options discussed thus far, what are the possibilities of actually reducing our energy requirements as a realistic approach to limiting the impacts of our energy use? In the coming years when dramatic CO_2 reductions are necessary and required under international agreements, it may be easier if we just use less power. Let us therefore examine what energy efficiencies we can realistically expect to achieve.

To understand the effect of various efficiencies, we need to know where the energy is being spent at the moment. MacKay looked at the energy use of a "moderately affluent" adult UK resident, as a world citizen. For our purposes though, we will look at the energy use of the average New Zealander. That is, we will divide consumption by total population - adult, child and baby.

So for a first estimate, we get a sector table from the Energy Data File of:

	kWh/d/p
Agricultural/fishing	4.7
Aluminium	3.0
Steel	1.6
Wood, Pulp, Paper Processing	3.0
Other Industry	21.0
Commercial	8.3
Residential	11.0
Aviation (fuelled in NZ)	2.6
Other commercial Transport	5.6
Retail Fuel	30.0
Total	90.8

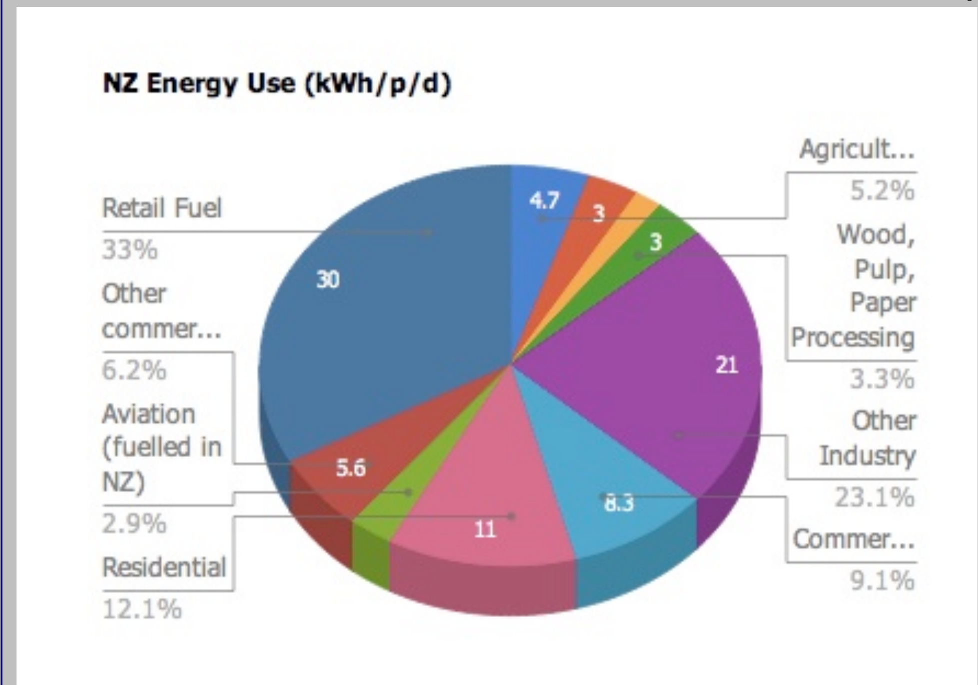


Fig.2 NZ Energy Use (by Sector)

Note: the small discrepancy in numbers (88 kWh/d/p mentioned elsewhere in this document vs. 90.8 kWh/d/p above) are from challenges in accounting for various sectors. It's in the ballpark however, so we thought it fine.

We can try to break these numbers into MacKay-like categories:

Cars

About a third (31kWh/d/p) of our total energy use is spent on vehicle travel, which is high by international standards. (This figure also includes some diesel purchases by small farmers and transport operators that are not adequately captured by other statistics.) By comparison, the average UK citizen spends 14 - 16kWh/d/p on personal vehicle travel. Consider that the average NZ car drives 18,000km in a year. If all were medium SUVs (0.9kWh/km) with 2 people in them, then this would translate into only 22kWh/d/p. It is clear then that we must make a lot of single-passenger trips in inefficient vehicles. Worse, this works out at a staggering 46kWh/d per vehicle (excluding mopeds, but including trucks)!

If spending on vehicle fuel is our largest energy use, how much scope is there for improvement? MacKay proposes that UK expenditure could be halved by electrification of transport, better cycle access and good public transport. Our low population density will limit the effectiveness of public transport and while we've made a bit of progress on building bicycle infrastructure, our focus is still heavily on vehicle infrastructure making bike-use less attractive.. We must surely be able to waste less than we do at the moment.

Electrification of Vehicles

McKay makes a strong case for the electrification of personal transport. Electric cars are 3 times more efficient at turning energy into motion than petrol motors, even when accounting for battery losses and transmission losses. When compared to other post-oil fuel sources (hydrogen, natural gas, biofuels, hybrids etc.) the benefits of electric far outweigh the negatives, and offer the 'path of least resistance' to uptake.

Most vehicle manufacturers have now recognised that electric is the way of the future and GM, Ford, BMW, Audi, Renault/Nissan and most other major car manufacturers are now intensely developing the technology and beginning limited production. Since 2009, the 'race' over the technology that will replace vehicle propulsion has been won by electric. However, the timeframe for the scale up is long, as it takes 20-30 years to replace the rolling stock from the point where they become the predominant technology.

Regarding the transition in New Zealand, it is likely that we will see greater adoption of electric cars as they become more economic. Currently the sticker price of electric cars is significantly higher than comparable models. This is primarily due the battery, which at half the cost of production is the single most expensive part of the car. We can expect this to come down over time.

The other relevant factor to consider is the impact of 'range anxiety' – electric cars have limited ranges compared to petrol cars which can just be quickly refuelled, and this is a concern of a lot of buyers. NZer's drive on average 50km a day, which is less than half the range of most electric cars on the market. For everyday use, electric can suffice. For longer trips – technology is improving all the time, and most electric cars now come with a 'fast charge' option that gets up to 80% of the charge within the first few hours. Tesla Motors has just announced new charging stations that can give three hours of driving after 30 minutes of charging. This is a fast developing area of technology. The other alternative is to rent a petrol car for longer trips.

In regards to the impact of electrifying transport on the grid, Transpower's Centre for Advanced Engineering has conducted studies to assess viability and how much, if any, new generation capacity would need to be built. They concluded that even in the 'high uptake electric vehicle scenario which sees over 390,000 electric vehicles on New Zealand roads by 2025, a maximum of only 180 MW of additional generation capacity would be needed - that's the size of two medium sized wind farms such as 'West Wind'. Further, the majority of the energy used for recharging would be at night when the grid is at its lowest and electricity is at its cheapest. The current wiring set ups in NZ households are capable of handling basic charging, but would need modification if they were to handle high voltage charging stations. [9x97yvx]

Like McKay in the UK, we think the case for the gradual electrification of New Zealand's transport networks is strong, but will depend on the developments of car manufacturers overseas bringing down the costs, the relative costs of other transportation and the business models that can be developed for a New Zealand context that can drive adoption.

The case for bicycles

Bicycles use only 1kWh/100km, or roughly 1/100 the energy a car uses [95nwj67]. McKay is a big fan of biking for its energy intensity and related health benefits. It is easy to imagine that NZ, with its outdoorsy lifestyle and temperate climate would be an excellent country in which to encourage more use of biking.

What are the things that we can do to encourage a greater uptake of bikes? A Rutgers University study of biking patterns in 100 US cities has shown that there is a strong correlation between the number of bike kilometres travelled and the level of bike infrastructure present (bike paths/bike stands etc.) [8597ys8]. A Ministry of Transport study has similar conclusions [9xghegt].

McKay makes a big case for the development of bike-friendly infrastructure and legislation, in the form of separate bike lanes, lower speed limits and collision regulations that favour cyclists. If we're going to increase biking as a viable transport option in NZ, we will need to take cycle infrastructure investment more seriously than we do today.

Improving our current vehicle options

When considering a car purchase, there are alternative strategies that can improve energy use. For example it has been noted that people tend to buy the car they want to use for holidays – and then commute in it. How about if we bought an efficient commuter vehicle and just hired an SUV for 3 weeks of holiday? According to the AA vehicle running costs report (AA members only, sorry), it works out something like this:

	Small car (1200cc)	Medium	Diesel SUV
Annual running costs	$7300	$11,100	$14,000

Three weeks hire on a Prado or Pajero would cost around $3000 plus fuel while a small SUV would be $2000. The philosophy of "commute in small and hire big when required" saves money as well as energy.

Being very optimistic, let's suppose that we can get energy use from car travel down to 15-18kWh/d/p by savings and improved technology by around 2030, a saving of 13-16kWh/d/p.

Q. Should I telecommute when that means heating my otherwise empty house, when I could drive to work and use their heating system instead?
A. If you work for 8 hours at home crouched over your one bar heater, you use 8kWh of heating. You spend the same energy driving 13km in a Yaris or 9km in a RAV. If it works for you, then telecommuting is a good option energy-wise.

Q. How much fuel do I save if I travel slower?
A. See MacKay's book for a detailed analysis, but considering air resistance only, fuel usage is proportional to square of speed. I.e. if you went half as fast, you would use a quarter of the fuel. In real-world performance, cars have rolling resistance. Most engines are tuned for an optimal revolution speed and gearing is designed for current road speeds. Nonetheless, travelling at 80kph instead of 100kph could deliver up to 30% fuel saving.

Planes

The 2.6kWh/d/p spend on aviation fuel, from the Energy Data File, is a very poor indicator of what New Zealanders actually spend on planes, because of airline fuelling regimes. For example, the return flight from London is included in the UK statistics. Data from the UN o96d[7t] and the International Civil Aviation Authority [8cc3859**]** gives an estimate of NZ passenger kilometres in 2004. Dividing by 2004 population converts to 18kWh/d/p using MacKay's estimate for fuel use. This includes energy spent overseas, and is a better indicator of New Zealanders' actual energy use on air travel.

To put long distance air travel in perspective:

Return trip to:	**Energy cost (kWh/d/p)**
Europe	56
USA	30 (LA, San Francisco) – 40 (New York)
Sydney	7
Fiji or Vanuatu	8

From an efficiency point of view, a full airliner is as efficient at per person/km as a car with 2 occupants. There is very little room to improve airline efficiency but assuming economic drivers push this to the limit, then perhaps the 2.6kWh/d/p figure, for airline fuel sourced in NZ, could be reduced to 2kWh/d/p.
We should note here that jet travel is one of the 'big ticket' items we have control over. One trip to Europe is the equivalent of nearly two thirds of a year of equivalent

energy used elsewhere in your life (assuming an overall figure of 88kWh/d/p). The best efficiency option is don't travel - use videoconferencing and virtual travel instead.

Commercial and Residential Energy Use

Making sense of the commercial and residential energy use in the Energy File is more complicated. All the commercial energy to light, heat, and power our gadgets both at home and at work amounts to 21.2kWh/d/p. Compare this with a UK usage of 37kWh/d/p for heating and cooling. A couple of caveats about these figures though. First, "industrial" energy use almost certainly includes some workplace heating, lighting and gadgets, so the real number is certainly higher. The number includes 5kWh/d/p of firewood but excludes firewood obtained from non-commercial sources. Using MacKay's estimates as a rough guide, we would break this down as follows.

Lights

The UK estimate is 4kWh/d/p for all lighting – work, home, and street. NZ is not so dark in winter. Assuming 5 hours of lighting in mid-winter, 0 in mid-summer, and 30% of days at work needing fluorescent lights on, then 2kWh/d/p looks realistic.

Gadgets (including work and school computers)

We are guessing our houses and work have pretty much the same list of gadgets that MacKay uses, but on a per person basis (using 2.6 persons per household from the census), I suggest 4kWh instead of 5kWh.The University of Otago's Home Energy Web Project estimates gadgets use at 19% power =2.4kWh. [8p45wmp] Add a similar number for work and 4kWh/d/p appears realistic.

Heating and Cooling

Subtracting lights and gadgets from the total residential and commercial energy leaves a total of 15kWh/d/p. Add in another 2 for industrial sources (e.g. factory heating) and 1 for private firewood and this gives an estimate of 18kWh/d/p - less than half the UK usage. While it certainly helps to live closer to the equator, it is also confirmation of what Europeans complain about – our houses are cold. Other studies (see below) would put home heating/cooling energy at 8kWh/d/p. If we use the same again for work, then this is 16kWh/d/p for heating, which in turn implies that gadgets (at work especially) and lighting might be more than estimated above.

Potential savings in commercial and residential energy use

So what efficiencies can realistically be made here?

The lighting figures already include some use of compact fluorescent bulbs (CFLs). In future, LED lights might reduce energy for lighting from 2 to 0.2kWh/d/p.

More and more, modern gadgets have advanced power management, but then we keep buying more of them. We strongly doubt that any significant saving will be made in this area.

Water heating is one place where significant savings can be made. As noted under the solar section, we have good solar water heating potential for many homes. A 50% take-up of solar hot water heating could close to 2kWh/d/p.

Refrigeration has room for improvement too. Fridges running on 0.1kWh/d/p have been achieved although at some cost in convenience. Nonetheless it seems realistic to expect that savings of 0.5kWh/d/p could be achieved with better design and placement.

Home heating is a more complex issue. A new house meeting the German Passivhaus [kWzrkz] standard requires less than 2kWh/d/p to heat, but the existing NZ housing stock will take hundreds of years to replace. Retrofitting to improve the heat retention of existing houses can be done, but I suspect that this will allow us to live with healthier temperatures rather than saving much energy. Finally, we can use air-source heat pumps to heat more efficiently. Saving even 2kWh/d/p for houses is probably optimistic.

There is quite possibly more potential for saving in the commercial and industrial sectors. Because of building density, the cost per person of putting in more efficient heating, lighting and power management systems is cheaper than doing the same thing to individual residences - but nowhere near as popular politically. Perhaps 4kWh/d/p could be gained.

In total, efficiency improvements from lighting, gadgets and heating might save 10kWh/d/p, much of it from workplace efficiency gains.

Just for people interested in what they have personal control over, here is the breakdown of average house energy use in NZ, again from the Otago Home Energy Web project [8p45wmp]. *(Note that the cost of this average energy use comes to about $2000 per annum, per household).*

Lights	*0.9kWh/d/p*
Refrigeration	*1.1*
Gadgets	*2.1*
Water heating	*3.2*
Heating/Air conditioning	*3.8*
TOTAL	***11.1***

The Royal Society of New Zealand has produced a teaching resource on energy use in New Zealand homes, which can be found at [8rxkn29]

One very important point to note here, if you want to make a difference – we tend to concentrate a lot on saving at home but this is only looking at 11kWh/d/p, and much of this is electricity already sourced from renewables. Per capita fuel use is 31kWh/d/p, which thus provides opportunities for far bigger savings.

Food

Farming and food processing cost about 8kWh/d/p of the NZ energy bill, much of which is of course exported. This is only energy consumed in food production – a great deal more energy is directly incorporated into our food from the sun. When looking at land for either biofuel or solar production, energy production competes directly with food. We could grow a lot more biofuel if we produced a lot less milk, for instance. For the purposes of national energy supply, we doubt much can be gained in terms of energy efficiency to support current production.

New Zealanders eat more beef than the UK population, but we eat next to no grain-fed beef and barning is rare. Overall, the 15kWh/d/p for a UK person is probably pretty similar here. Reduce that to 10 for vegans, but remember that crops cannot be grown on much of the land that we graze (especially not continuously).

Stuff

The remaining energy budget, 28kWh/d/p, disappears into concrete, steel, cement, and our industry, which we can term - making stuff. Buying less stuff would obviously reduce energy demand, but it is hard to otherwise identify what saving can be made in this area in terms of efficiency. Energy cost is a significant factor in making stuff so economic factors usually work to maximise efficiency in the larger scale projects.

Not included in the 88kWh/d/p from the Energy Data File is the energy that we *import* as stuff. We are burning coal in China for every Chinese-made appliance or clothing item that we buy. MacKay estimates 48kWh/d/p at least. Looking over our list of "stuff", we would have to conclude "at least" as well. It is hard not to conclude that a significant way to reduce energy use in China would be for us to buy less stuff, buy stuff that will last, and use it for a very long time. Tossing out a cellphone or laptop because the battery has run out is not good but product lifecycle data suggests that this is what many people do. The average lifetime of a cellphone is 18 months (or less if you buy a new iPhone every time it comes out!). This calculation of 48kWh/d/p though is tough and we have considerably less confidence in it compared to other calculations we have used.

We, like McKay, don't have any concrete suggestions for how to reduce this other than to encourage less consumption of this 'stuff' and to buy things of higher quality that will last longer.

Summary of Energy Use

Using the MacKay categories (but ignoring imported goods and energy spent overseas on air travel), our total energy use of 88kWh/d/p breaks down as shown in Fig.3:

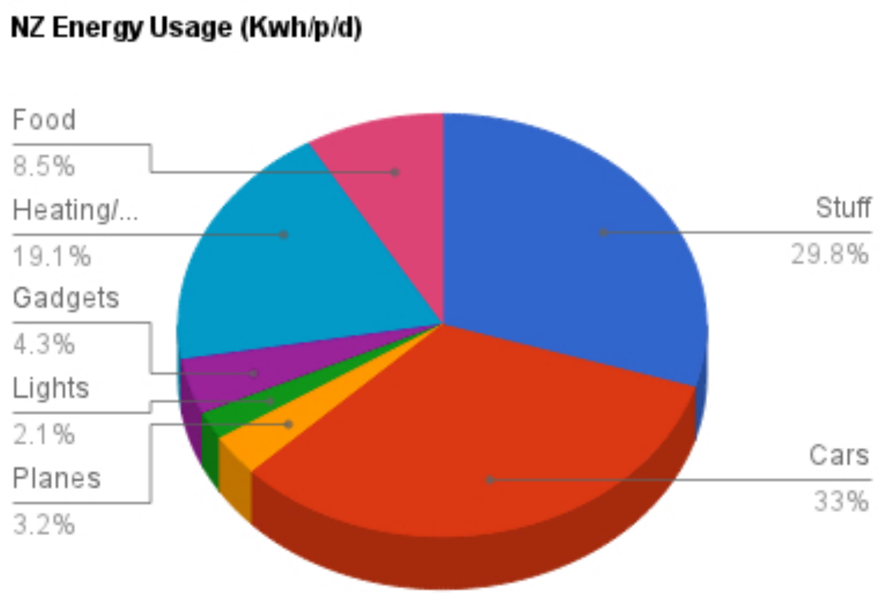


Fig.3 NZ Energy Use (by end use)

Summarizing the data above into what energy the average person has personal control over (excludes industry, work place etc. but includes the embodied energy of our personal paraphernalia, and energy spent overseas on air travel), we get Fig.4, or 129 kWh/d/p. We used 2005 International Civil Aviation Authority and 2004 UN data on NZ passenger kilometres for the calculating the average air use by a New Zealander. [8cc3859]

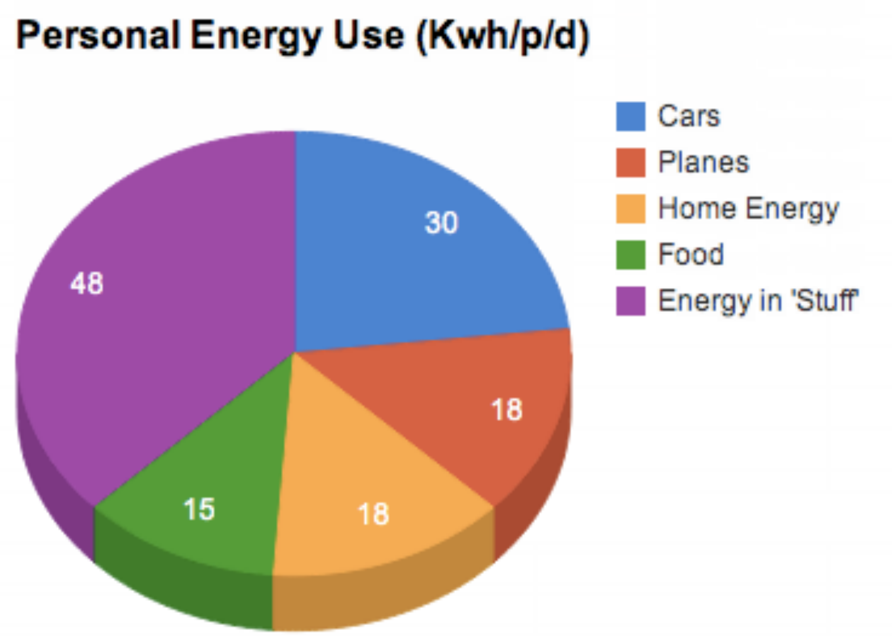


Fig.4 Personal Energy Use (including imported embodied energy and energy spent overseas on air travel)

For anyone interested in how they might compare to Mr and Mrs Average, the important calculations are:

1) Cars: Get last year's registration and calculate kilometres travelled in a year for all your cars. Divide by 365 and divide by (no of people). Multiply by 0.65 for small car, 0.85 for SUV.
2) Planes: Total kilometres flown in a year, per person, multiplied by 0.00145.
3) Food: Reduce to 10 if vegan.
4) Home energy: (Total annual kWh from electricity bills + non-electric heating kWh for year)/365/no of people. (Heating cost: 1 cord of firewood is about 6000kWh, $1m^3$ is about 1600, 50kg of gas is about 650kWh.)

Lifestyle blocks – a perfect storm for energy inefficiency?

Lifestyle blocks, especially on arable land, are a particular problem for NZ. Virtually all renewable energy sources require a lot of land which puts pressure on our current production. A lifestyle block typically turns productive farmland into pet food. Few are truly farmed and so the occupants then typically commute for work, education and entertainment. Worse still, the commuting is often in an SUV, justified because of the farming lifestyle. Paradoxically, lifestyle block owners might espouse green values, ("grow all my own vegetables") and may even be off-grid for power. Sadly, the high energy use associated with commuting probably negates the savings in other areas. For example, a block located 25km from work could cost 45-50kWh/d for only one return trip a day compared to 11kWh/d/p saved by being off-grid.

Summary of Efficiency savings

It seems possible that a saving of about 25kWh/d/p is achievable. (This comes from 15 for cars and 10 for gadgets, lights and heating – ie, not including other potential savings in energy spent overseas by New Zealanders) This is a significant dent in the 64 kWh/d/p of non-renewable energy use that we wish to eliminate, but note that half of it depends on the eventual uptake of electric vehicles which are still a while away. We should also note that reducing our consumption of 'stuff' (currently around 48 kWh/d/p) is a great way to reduce overall energy intake – reduce, reuse, recycle!

What might it cost to achieve an all-renewable energy economy?

Costs are highly dependent on what exactly our energy plan is but here is an example of a plan which could be reasonably executed by 2025, consisting of a range of both generation and conservation measures. The plan is chosen to illustrate the relative cost-effectiveness of various options – we are not suggesting that this is the plan that NZ should adopt, merely to give an indication of what a workable plan might cost.

	kWh/d/p	Cost($B)	Cost per kWh/d/p ($B)
Build top 8 hydros	4	5	1.1
Windmills (All of Tranche 1)	32	37	1.1
Windmills (~50% of Tranche 2)	5	9	1.8
Geothermal	4	4	0.8
Solar hot water on 740,000 homes	2	4	2
Insulate remaining homes	2	2	1
Electric cars phased in over 20 years	10	0 – 5	0 – 0.5
Solar photovoltaic	2	9.6	4.8
Conservation (lights/refrigeration)	1	0	0
TOTAL	**62**	**70.6-75.6**	

Some notes on the options:

Hydros: The schemes costed here are Lower Waitaki (in process), all 4 schemes on Clutha, Mokihinui, Wairau and Arnold.

Windmills: Tranche 1 is the several thousand windmills which can generate at 8c/kWh, while Tranche 2 can generate at 10c/kWh. These are largely located in Hawkes Bay, Manawatu, Wellington, Northland and Southland. Around 60-65% are in the North Island.

Geothermal: This is all the schemes which could be consented within current resource management law.

All pricing is from the Electricity Commission TTER studies [8rcht8w].

Solar hot water: This is estimated for half the homes in New Zealand, assuming that installation will happen at the same time as a water cylinder is replaced and so the marginal cost for each installation is $5000. The payback time for a homeowner doing this is 7-12 years. [p266yw]

Insulation: An estimated 1,000,000 homes are still not properly insulated. Cost was based on the average cost of the home insulation scheme running since 2009, which was calculated to be around $2000 a home (or $1700 for North Island homes, and $2300 for South Island homes using the BRANZ average of 150m squared.). This brings the total to around $2 billion of further spending to ensure all homes are insulated. The savings are much harder to calculate. It is possible that energy costs will reduce very little, but more homes will be warmer and healthier, saving health costs but not energy.

Electric cars: These are not even with us yet and another possibility for NZ would be biofuels. However, worldwide conversion to biofuel would seriously impact on already stretched food production so electric cars are more likely as mentioned earlier. The cost estimate is so wide because of the assumptions needed. If we were to replace the entire car fleet with electric vehicles right now, at an assumed cost of $60,000 each (cost of the Mitsubishi Miev), then it would cost $138 billion. However, even if we wanted to do that nobody makes that many electric cars! – even GM, the biggest electric car maker with its Volt only makes 45,000 cars a year at the moment (while we have 2.3 million cars), and I'm sure there would be issues with farmers if we tried to replace their utes with small commuter cars. So it's more realistic to think of the transition over a 20 year time frame. Almost all of the cars in New Zealand will be replaced in this timeframe anyway.

If electric cars were of similar cost and bought in a similar way (including used imports from Japan), then the marginal cost of the change could be low as we'd only need to retool certain aspects of our infrastructure (such as putting in charging stations at homes and workplaces). Currently electric cars carry a premium of anywhere from 30-100%. If we calculate the transition over 20 years with a scale up from 1% to 100% of our new vehicles sold being electric (currently~150,000/year) and costing 100% more in the beginning (and this coming down to be cost competitive with petrol in 20 years), a more reasonable figure is a cost of **~$5 billion.**

One potential option for scaling up electric car use is being developed by a US-based company called Better Place. Launched in 2007, it is working with automakers Renault and Nissan (as well as others) to develop solutions for the biggest barriers to electric car adoption, namely high initial costs and limited range. They have developed battery swap stations so that consumers can quickly switch batteries to extend their vehicles range, in addition to offering home charging options. Better Place owns the batteries, and charges users a subscription (much like a cellphone plan) for a certain number of kilometres a month. The car cost is lower, as it doesn't have the cost of the battery included, and the driver doesn't need to worry about range, as they can switch out batteries when they want to travel for long distances. Better Place has operations in Australia, and has estimated that the cost of 500 battery stations (providing the same level of coverage as the 13,000 petrol stations) for the entire country would be in the region of $1-1.25 Billion AUD. Scaled down to NZ size, that is an investment of approximately $250 million (enough for about 100 battery switch stations in addition to the home charging stations) spread over a number of years as adoption rates scale up.

The marginal cost of the electric vehicles is a lot lower than current electric vehicles (especially if can to buy them on the second hand market), and the currently limited selection will increase over time. We don't necessarily support Better Place over other options, but it is interesting to see that the marginal cost of electrification could be relatively low (especially when we see that we currently spend $7.7 Billion a year importing oil, of which the majority goes to transport).

The savings (10kWh/d/p) are very conservative and could be twice that.

Solar PV: Getting 2kWh/d/p would need 20m^2 of the conventional, cheaper solar panels on about half the houses in NZ. With an installed cost at today prices of $13,000, this is nearing the point where it will make sound economic sense for a lot of homeowners. [8qadyqh]

Conservation: The cheapest option but it is hard to make a significant difference. This figure assumes rigorous adoption of better lighting, refrigeration, and efficient gadgetry over a normal replacement cycle in both residential and industrial usage.

This plan calls for a seriously huge number of windmills (10,000+) with all the issues associated with wind variability and backing capacity. In practice, more hydro and geothermal may be required unless a serious contribution can found from either conservation or other generation.

Just to put the numbers in perspective, here are some other large numbers drawn from the 2011/12 budget:

	Cost ($B)
NZ GDP	*177*
Education	*12.4*
Health	*14.7*
Transport (not including spending on Roads of National Significance)	*2.2*

And a not so large number:

Sustainable Energy R&D	*$B 0.032*

The first goal would be to end electricity generation from coal and gas (6kWh/d/p). We could achieve this by efficiency alone or build more renewable generation. Wind is probably the fastest route, with geothermal and hydro options to follow. The complex issues are balancing biodiversity with economics in new generation, and in setting national priorities. The elephant in the room is population. Living on renewables is relatively easy for our current population of 4.4 million. Doing the calculations for 14 million would be more difficult. To maintain the country in even close to its current state, we need to constrain population growth as a priority.

Making a BIG Difference

Media messages make it all too easy to believe that by merely turning off our TVs and installing energy efficient light bulbs, we can become sustainable for energy. Achieving this is actually somewhat more difficult. What do we need to do, both as individuals and as a nation, to make a big difference to our energy problem? Based on the numbers presented above, we have compiled the following lists.

Individuals
• Small family size. • Reduce car usage. eg Telecommute Walk/Bike/Public transport Live close to work Car-pool • Get the most fuel-efficient vehicle possible. Stop kidding yourself about that SUV. Rent 4WD when required. • Avoid air travel – remember a trip to Europe can be the biggest single 'ticket item' in your personal energy use. Enjoy New Zealand or sail the Pacific. • Less stuff – choose goods with a long lifecycle, made using renewable energy. "Reduce, reuse, recycle"
• Insulate. Use a heat pump or woodburner for heating. • Install solar or heat pump hot water heater when you replace hot water cylinder. • Replace whiteware older than 10 years with modern maximal efficiency equivalents. • Avoid meat grown on land that would sustainably grow other food. • Minimise house size.
• Replace lighting with high efficiency types. • Install plastic sheeting on the outsides of window frames to minimise heat loss through windows. Even better, install double-paned windows.

Workplace
• Prioritize travel. Invest in videoconferencing. • Travel should never be an employee reward. • Enable telecommuting.
• Workplace sustainability groups. These operate like workplace productivity or health and safety groups to audit and advise management on better practice. Landcare Research and GNS Science both have such groups. Best of all, they can save companies money by identifying energy wastes.
• Replace lighting with high efficiency types.

Communities/Local Government
• End urban spread - especially onto arable land. • Build cycle ways, cycle stands and efficient public transport.
• Prioritize renewable generation sites to reflect economic, biodiversity and amenity values. • Build your own windmills. • Recycling schemes. • Encourage solar installations by reducing consent fees.
• Regulate for passive house design.

Central Government
• Build/incentivise renewable generation. • Electrification of transport. • More national funding/strategic planning of cycle infrastructure. • Strengthen ETS to price carbon.
• National prioritization of renewable generation sites.
• Subsidise retrofitting of old houses for energy efficiency.

OTHER RELATED READING

The New Zealand Parliamentary Library published a paper on the vulnerability of New Zealand's economy from peak oil in 2010. We're pretty exposed given our reliance on cheap fossil fuels to drive tourism and certain types of export. It is a well-written and concise document well worth a read. Can be found here: [2eqj8w4]

Do the Math is a website maintained by Tom Murphy, an Associate Professor of Physics at the University of California San Diego. Tom taught a class in 2004 on "Energy and the Environment" and in his preparation for teaching started research into post-oil/renewable energy sources. He was dismayed to find there was so little research going on given the scale and importance of the issue. Do the Math is an excellent collection of both global and household analysis on energy, growth and options for generating energy in the future. His website can be found at http://physics.ucsd.edu/do-the-math/