A Few Facts About Renewable Energy

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Taupo, New Zealand

2nd October 2004

- There are two main public policy reasons why governments are concerned about our reliance on fossil sources of energy: security of supply; and environmental impacts (most notably greenhouse gas emissions).

- Resource limitations do not appear to be a compelling reason for concern at the global level given the scale of coal resources and the potential for further oil and gas discoveries as well as of oil substitutes. I appreciate that this is a contested statement but from my reading of the debate there is not a problem within any sort of timescale that normally intrudes into political thinking. This paper proceeds on the basis that security of supply and climate change worries are the principle reasons for a search for non-fossil alternatives.

- These two concerns have, in different ways, thrown the spotlight on renewable sources of energy. Where are we at technically and economically?

- The RT on SD that I chair has just had two meetings on this subject – I'd like to use this meeting to share some of the findings with you. The first meeting focussed on the barriers to a greater market penetration by renewable energy sources, especially for electricity generation. The second discussed the future of the road transport sector with a particular focus on whether liquid fuels could be placed on a sustainable basis or, alternatively, replaced by some sort of system based on hydrogen.

- But before I turn to the conclusions of those meetings, I'd like to give you a sense of the relative size of the renewable resource both at the level of the planet, and at the level of New Zealand. I want to do that because I find that most people have very little idea of the actual potentials available and what can plausibly be harnessed. There's a sense that "renewables are a *good thing*" but the reasons why they don't command a bigger market share are often vaguely understood.

- The source of most renewable energy is the sun. The solar flux that reaches the upper atmosphere of the earth totals 5.4 billion PJ/year – a stupendously large figure. But because the earth is a rotating sphere, and because a large amount of the incoming radiation is radiated back into space, the amount actually reaching the earth's surface is about an order of magnitude less – some 682 million PJ/year. Professor Ralph Sims at Massey has usefully described a petajoule as being a unit of energy roughly equivalent to all the crude oil in a large tanker. That much is comprehensible but if you can imagine 682 million oil tankers – let alone 5.4 billion of them – you're doing better than me!

- After direct solar radiation come the secondary flows of solar energy – the kinetic energy contained in rivers, winds, and ocean currents, and the net photosynthesis of all terrestrial ecosystems available as biomass. Here are the numbers[2] [Table 1]:

    - Wind flows of around 4 million PJ/year

- Net terrestrial photosynthesis of around 2 million PJ/year
- River flows equivalent to 35,000 PJ/year
- Ocean currents: we simply don't know. They're significant but mostly beyond technical reach.

- To round out the renewables we need to add two non-solar sources:
  - Geothermal flows around 4400 PJ/year
  - Tidal friction of around 100,000 PJ/year

- It's against these orders of magnitude that it is interesting to set our current reliance on energy from fossil fuels. Fossil fuel generation expressed in the same terms provides a power flux of 310,000 PJ/year. So it lies ahead of river flows but behind wind flows.

- These renewable potentials are theoretical maxima. Only a fraction is ever going to be practically available (for a host of physical, technical, economic and environmental reasons). Most of the wind, for instance is so far above the planet's surface that it is forever beyond reach. Most of the tidal friction is dispersed at incredibly low power densities.

- But it's still useful to understand the relative scale of these fluxes. And on this basis we can say that fossil energy use is 0.1% of the solar radiation that reaches the planet's surface. But it's already ten times bigger than the total theoretically available river flows of the world.

- Looking at some of these large numbers – especially solar and wind energy – you might ask why, if there is so much of the stuff, aren't we using more of it? Why rely instead on the accumulated solar radiation stored in fossilised plants over hundreds of millions of years? It all comes down to the density of the power we are trying to intercept. Figure 1 illustrates the point.[3]

- In a nutshell, renewable energy sources (other than geothermal) are spread out over huge areas making it physically very difficult to harvest them.

- Because fossil energy is so dense, we've built our society around final energy uses with correspondingly high power densities. Figure 2 superimposes some of those uses on the energy density figure.

- Take houses for instance. A century ago many houses had an installed electrical capacity of as little as 500 watts – enough for some low power light bulbs. Today the installed capacity of a large house can be as high as 20,000 watts or more (especially in countries like the US where affluent households increasingly opt for fully air-conditioned living environments). That's a 40-fold increase.

- The same phenomenal demand for non-electric energy applies to transport, most obviously private motor vehicles. Professor Vaclav Smil (from whose excellent recent book *Energy at the Crossroads* I have abstracted many of the numbers for this speech) has estimated that the sort of energy at the disposal of an affluent US household today (counting in house, motor vehicles and the technological paraphernalia associated with many outdoor leisure activities) would, in Roman times, have required the services of about 6000 slaves![4]

- What, then, is known about the potential for our vast but highly dispersed, low-density renewable energy sources to make significant inroads in the demand for fossil fuels (which, by the way, are forecast to rise from 310,000 PJ/year to well over 500,000PJ by 2030)?[5] [Table 1]

- Of some renewables, like ocean currents and tidal friction, we can't really say anything sensible. The only thing more problematic than the estimates is the technical challenges that are posed.

- The potential of geothermal resources is better described. At the level of planetary energy demand, it is very small although clearly significant for some countries – including New Zealand.

- With hydro power the potentials become much better known. At the global level, 25% of the world's hydro-energy potential has already been harnessed.[6] While there will undoubtedly be more dams, environmental, social and political limits mean additional hydro is unlikely to make a significant additional contribution to energy supplies.

- Hydro-power has an inherently low density with installed capacity of around 4 W/m^2 and actual production of around 1.7 W/m^2 when spread across the 600,000 km^2 of reservoirs that exist behind large (i.e. >30 metre high) dams. (That, by the way, is an area twice the size of Italy.) Compare that 1.7 W/m^2 with fossil fuel's equivalent density of about 1000 – 10,000 W/m^2 and you see the gap.

- How about bio-mass? Terrestrial photosynthesis produces 6 times as much energy potential annually as the world consumes in fossil fuels.[7] That's roughly 2.0 million PJ/year. The trouble is that about 40% of that is already appropriated for activities like farming, forestry and other managed land use activities. Much of the rest supplies vital ecological services not to mention representing a vast reservoir of bio-diversity. So there are real limits to how much of the planet could be converted to producing bio-mass for energy – and that's without getting into the side-effects of additional fertiliser use etc.

- Bio-mass also has very low energy density – about 1 W/m^2 for the most productive crops like corn for ethanol – but by the time it has been converted either to liquid fuel or combusted for electricity with co-generation, the efficiency drops back nearer to 0.5 W/m^2. If you then take account of the energy used in producing such crops the power density may shrink down to as little as 0.05 W/m^2.[8] The amount of bio-mass currently being tapped is about 40-45,000 PJ/year, most of this in the form of direct combustion of wood in developing countries.[9] Much of it must be regarded as unsustainable.

- New bio-technologies that convert cellulose into ethanol might improve the power density of bio-mass by substantially increasing the amount of biological material that can be used as feedstock. But those technologies are not yet economic.

- Next comes wind. At the global level the flux is vast – say 4 million PJ/year. But most of that is unavailable for exploitation. Restricting the available resource to winds in excess of 5 m/s and within 10 metres of the earth's surface would, it is estimated, yield about 186,000 PJ/year. That needs to be compared with current fossil electricity production of around 36,000 PJ/year.[10]

- Despite major strides, wind power suffers from the inherent problem that it is variable, unevenly distributed and its highest potentials are often far from where really large consumer populations live. Needless to say, only a fraction of the available potential can ever be harnessed.

- Finally there is solar power of which, you will recall, there is 682 million PJ/year reaching the earth's surface. The global mean energy reaching the surface averages 168 W/m^2. That is a higher power density than any other renewable energy source. Obviously there is no 'average' available to intercept. There is more energy to intercept in the tropics than polar latitudes in winter! But even now, it is possible to covert solar radiation to electricity at densities well below that average – in the range of 20-60 W/m^2 – so there is plenty of scope for improvement.

- Set alongside this huge potential, current global electricity generation from solar radiation amounts to barely 0.1% of total generation. Or taking the global demand for energy of all types, renewables according to the IEA provide just 13% and that includes a large chunk of distinctly low-tech – or more accurately pre-tech – burning of wood.[11] In short, renewables provide the least significant share of the planet's energy needs.

- That, in a sense, is all by way of introduction. The key point to make about renewables is that while their potential is enormous, the share that can practicably be tapped is much, much smaller. Furthermore, their usefulness is not spread evenly across the surface of the planet. Their availability varies depending on latitude, topography, the hydrological cycle and so on. So any proposed "solution" to the world's energy problems based on renewables will be 'regional' in flavour.

- Remarkably, the shape of the renewable potential on a country-by-country basis is largely undescribed, even for countries like New Zealand. To give these abstract planet earth level numbers a more realistic feel, I set out – with the help of the IEA and Professor Ralph Sims from Massey University - to construct a picture of the potential here in New Zealand. Here [Table 2] is the best estimate we can presently produce for –

- The total energy flows for each of the ‘renewable’ sources
- The theoretical maximum that might be available using known technologies
- The plausible economically exploitable yield of energy given human and environmental constraints
- The present level of exploitation

- The point of the exercise is, again, to give a feel for the relative scales involved, not to predict or promote any particular energy future.

- So much for the physical constraints. What about the economic and policy constraints? Why haven’t renewables made more headway?

- As I have indicated, there are two main reasons you might want to see renewables make more headway: firstly, a concern about the environmental consequences of burning fossil fuels, especially greenhouse gas emissions; and secondly, concern on the part of some countries that (especially in respect of oil) they are overly dependent on energy supplies from very unstable parts of the world.

- On the environmental count, the problem is that the things that make renewables preferable to fossil fuels are often given no ‘value’ in the marketplace. As economists would put it, fossil fuels are not exposed to their true environmental and social costs. Or more bluntly, people may believe CO_2 emissions are a bad thing but there’s no financial penalty for emitting them.

- I don’t intend to pursue the climate change debate here. Most governments believe there is an issue to be dealt with. The debate is over the potential seriousness of the environmental impacts and the speed with which emissions reductions should be pursued. Rarely spelt out clearly is the practical issue that measures designed to reduce emissions have costs that are hard to quantify and even harder to weigh up alongside other valuable objectives that may also entail costs.

- I acknowledge that there are those who believe there is no problem – or if there is, it’s not worth worrying about. I am not of this view. But if you were, you would argue that renewables should take their chance in the marketplace and whether they will ever come to play a more significant role is going to be up to the ingenuity of researchers, engineers and investors.

- That still leaves security of supply as a possible reason to take an interest in renewables. But in many countries – New Zealand being one – if you knock concern for CO_2 emissions off the table, the existence of huge coal reserves and the probability of significant unproved conventional and unconventional hydro-carbons means renewables would not merit any special attention.

- The balance of this talk proceeds on the basis that burgeoning greenhouse gas emissions *do* pose a problem. In the short to medium term we will still be reliant on fossil energy. The key will be to seek the least carbon-intensive sources (like gas) and use them as efficiently as possible. But we will also need to make much greater use of renewables over time. The question is: how do we make that transition. If there was a really high level of engagement and concern by governments, you would expect them to increase the cost of emitting CO2 and other greenhouse gases to the point that renewables became competitive.

- You will all be familiar with the tools available to do this - taxes or permits whose effect is to raise the price of emissions. I won't say any more about these eminently rational economic instruments other than that most countries seem to find then intractably difficult to introduce. They're so sharp and so transparent that beyond very modest levels they run into fierce opposition from consumers and also from businesses who have to compete with operators in other countries who don't carry these costs. Unless there is some global agreement gradually to increase the price of CO2 emissions, I can't see significant progress along this path.

- Which leaves governments trying to find other – second best - ways to bring renewables into the market in the face of competition from cheap fossil fuels. Last week in Paris, the Round Table I chair held a meeting to discuss what might need to happen if the first best 'rational' tools like pollution taxes aren't used. To provide some basis for our discussions we commissioned a paper from Dr Karsten Neuhoff at Cambridge University. The paper is available on the Round Table's website[12]. Those interested in the details should read it carefully but in a nutshell he advanced three priorities.

- The first was to remove any marketplace barriers to greater penetration by renewables. For example, in many countries, energy markets have developed to accommodate energy supply from large thermal generators whose supply is easily predicted and pre-sold a day in advance. Wind power is less predictable – by the time it can be predicted with reasonable accuracy (within about 4 hours of production) the trades have been done. Yet from a technical point of view, transmission flows can be adjusted within seconds and generation from traditional plants can be adjusted within the time-frames in which wind can compete. It may be necessary to examine the way the market works. It may also be necessary to investigate the extent to which traditional generators can use their market power to lock out new entrants.

- The second was to address barriers to renewable energy that are rooted in sociological or attitudinal problems. These can range from community fears about the risks – real or imagined – of new forms of energy to opposition to landscape effects. I understand New Zealanders are no strangers to this aspect of the debate.

- Finally, there was the issue of what has been termed ‘technology lock-in’ – the simple fact that in the absence of paying their full environmental costs, traditional energy sources have the almost insuperable advantages of having been proved, tested and improved over very long periods. The technical gaps for renewables will take time and a large amount of ‘learning-by-doing’ to catch up.

- Whether that learning ever takes place is the question. That’s because something like electricity is a commodity. Electricity producers can’t compete as their electronics sector counterparts do when they launch a new product by differentiating it with all sorts of consumer-friendly features and charging a premium to justify the research costs. Electricity is electricity. It’s either cheaper or it’s more expensive.

- It’s also appears to be harder for energy technology developers to stop competitors benefiting from technology spill-overs. Whereas the pharmaceuticals industry has been able to use patents very effectively to recoup the costs of developing new drugs, this approach seems to work less well in the engineering sector. Where sectors like pharmaceuticals and IT seem to be able to devote more than 10% of their sales revenue to R&D, the figure for electricity generation R&D is below 0.5% of sales.

- Considerable attention was paid, at our meeting, to how governments can tilt the playing field enough to enable renewables to get the sort of practical track record that their competitors (often with government subsidies decades ago) have benefited from. The cost of new technologies falls as deployment increases as Figure 3 demonstrates. The percentages show by how much costs have fallen with each doubling of global production.

- But if the gap is too big to start with, deployment may never get off the ground. Interestingly, Denmark – which consciously set out to encourage deployment of wind turbines – did so initially, not for environmental reasons, but security of supply reasons in the wake of the first oil shock. Thanks to their subsidies and encouragements (and those of a few other countries) we now have wind turbines that can compete with traditional energy sources.

- The simple question for policy makers have to confront is this: if they are not prepared to price environmental costs into energy prices, then they may have to use other means of bringing novel energy sources to the market place. Otherwise, the price advantage of fossil fuels will perpetuate the technology lock-in. The tools for doing this involve things like requiring energy suppliers to deliver a percentage of their power from renewable sources. The pros and cons are spelt out in Dr Neuhoff’s paper.

- My comments to this point have related to electricity generation. With roughly two thirds of global electricity generation based on coal, gas and oil, increasing the share of renewables in electricity generation would clearly provide a useful means of tackling CO_2 emissions.

- But electricity makes up only 15% of final energy consumption at the global level and electricity generation is responsible for only about 43% of total CO_2 emissions. By fuel, the single biggest contributor to these emissions is oil, and nearly 60% of this is used in transport. So the quest for a larger share of renewable energy has to address not just electricity generation but mobility and here the problems of technology lock-in are if anything even more difficult.

- This has been the subject of a recent study conducted by 12 large automotive and energy firms entitled *Mobility 2030 – Meeting the Challenges to Sustainability*[13]. This report was the subject of my second Round Table meeting. The study – a $10 million project whose sponsors included eight of the world's largest automobile companies – looked at mobility in the broadest sense and defined sustainability to include a wide range of issues including things like noise, safety and congestion.

- Given the particular expertise and focus of its sponsors, its most detailed analysis focuses on road transport which is responsible for the bulk of emissions and will be in the future. It is a large and fascinating piece of work which could be the subject of an entire conference. All I'd like to do here is focus, once again, on the security of supply and greenhouse gas emissions issues. Interestingly, many of the other challenges such as health and environmental risks from local emissions and particulate, noise, safety and congestion look, to varying degrees, to be soluble. It's the ghg emissions issue that looks the most difficult.

- The reasons are once again to do with technology lock-in but in a much more severe form. Where electricity generation uses a variety of technologies and energy sources (fossil fuels, uranium, geothermal, water, wind and the other renewables), transport is massively dependent on liquid fossil fuel. And where electricity generation is achieving conversion efficiencies of up to 40-45% for combined-cycle gas plants, transport modes relying on oil derivatives are no more than around 10 - 15% efficient.

- Yet we have increasingly constructed our entire civilisation around mobility systems that rely on liquid fossil fuel. That has affected the pattern of all urban growth over the twentieth century. The sheer freedom that mobility has given people has virtually re-defined what people define as their well-being in every country that has become motorised. And the ability to move people and goods over large distances has become the engine of economic development – some studies suggest transportation may be responsible for as much as 50% of all economic growth in some advanced societies since the Second World War.

- The lock-in here is as much cultural as it is technological – and it appears to be global. The project's sponsors, working with the IEA, commissioned quite a bit of modelling work to flesh out the transport module of the IEA's global energy models. The results are stark. A business-as usual base case which allowed for the sort of efficiency improvements which occur 'naturally' given technological improvements, predicted that transport (measured in tonne-kilometre/years) is likely to treble between now and 2050 [Fig. 4]. Passenger kilometres per year are forecast to double.

- Needless to say this growth is accompanied by massive growth in emissions. Notwithstanding improvements in per unit energy consumption of 18% for light duty vehicles and 29% for trucks and aircraft over the period to 2050, the sheer growth in predicted transportation swamps these gains and delivers a more than 100% increase in emissions. [Fig. 5] Most of this growth, not surprisingly, is in developing countries [Fig. 6]

- To the challenge of emissions growth has to be added security of supply risks. Unlike the resources needed to generate electrical energy, the liquid fossil fuel needed to power the transportation system is not spread evenly around the planet.

- As we are reminded almost nightly, the most accessible remaining reserves are largely concentrated in highly unstable parts of the world. We have placed a lot of eggs in the same basket.

- The industry study concluded that while there are useful incremental gains that can be made from new technologies that are becoming available (like Toyota's gasoline/electric hybrids), and while governments can influence their take-up by fiscal and/or regulatory instruments, these won't be enough to shift the emissions trajectory away from an inexorably rising path. Only recourse to radically different fuels and/or power-trains can do that – both involving renewables.

- The study sketches two broad possibilities – advanced bio-fuels and hydrogen from carbon neutral sources. Both offer useful possibilities – both run up against significant problems. Bio-fuels have an immediate attraction in that they are liquid fuels and hence, potentially compatible with the current shape of our fuel distribution system and of course bio-fuels are already used (sometimes extensively as in Brazil where all motor fuel contains over 20% ethanol).

- But as we have seen, conversion of large amounts of bio-mass to energy would run up against physical constraints. If we are already appropriating roughly 40% of the planet's terrestrial photosynthetic output, how much more can we appropriate whilst producing the food and other biological products we need as well as maintain biodiversity and ecological services? Advanced bio-fuels seek to minimise these pressures by greatly increasing the range of raw biological material that can be used as feedstock including crop residues and animal wastes (thereby de-coupling bio-fuel production from food production) and improving the energy density of the fuel through improved conversion processes.

- In this connection the report mentions two promising technologies – the enzymatic conversion of woody lignocellulosic material to ethanol and a range of chemicals (which would allow a wide range of biological waste material to be used rather than specific fuel crops); and biomass gasification followed by a biomass-to-liquid process (imaginatively known as BTL). As the report notes, neither of these processes has been proved on a commercial scale and there are a host of technical challenges that stand in their way. There would also be massive logistical and social consequences if we started to move around the volumes of biological material that would be needed to make a significant contribution.

- But even assuming those challenges can be overcome, there are still the inherent limits of biomass production on the scale required. To quote from the report: "A world scale BTL plant (one capable of producing 1.5 million tonnes per year) would require woody biomass collected over an area half the size of Belgium. Alternatively, a world scale lignocellulosic fermentation plant (0.2 million tonnes per year) would consume surplus straw from a planted area of wheat approximately one tenth the size of Belgium."

- Hydrogen from carbon neutral sources is possibly more hopeful but starts with the handicap that it is not only incompatible with existing liquid fuel reticulation systems; its most practical use envisages a complete shift away from the internal combustion engine to fuel cells. In the immediate future, fuel cells offer the most efficient way forward since vehicles can capture 40% of the available energy as against the 10-20% ICEs use. But again, the gains are only incremental if the hydrogen is sourced from fossil fuels like natural gas.

- The silver bullet solution, if there is one, would be to make hydrogen from water by electrolysis with the huge quantities of electricity required to do that coming from renewable sources (which brings us back to wind and, above all, solar power). But given the current state of solar electricity generation technology, that is a distant prospect.

- The most interesting element of the *Mobility Project* was its attempt to give some feel for what it would take to bend the road transport emissions trajectory back down to current levels by 2050 (assuming the growth in demand for transport they projected). First they looked at the impact of single technologies – both incremental and radical. As you can see, only the technologies that rely on renewable energy move the trajectory in the right direction. [Fig .7]. (It is important to note that this is an entirely hypothetical representation assuming that each alternative technology achieved virtually 100% market saturation. Obviously this wouldn't happen.)

- Then they took a stab at a more plausible forward projection that assumed five incremental technology-based gains and two 'increments' relating to fleet mix and more efficient traffic management respectively. You can see [Fig. 8] how bio-fuels and then fuel-cell hydrogen are sequenced to appear from 2020 onwards and how, as they are progressively based on low greenhouse gas sources, the trajectory turns down.

- Needless to say, this is just a model run based on some very challenging – but still plausible – assumptions. The question remains, however, how in the real world we might get there. Bearing in mind the case made earlier for 'strategic deployment' of electricity generation, it is interesting to note the *Mobility Project*'s sober assessment of this option with respect to the advanced hydrogen and bio-fuel options based, as they are, on renewables:

- "The SMP assessment is that the most accurate judgment that can be made at present about these advanced vehicles and fuels is that their current costs are much too high for them to compete in the marketplace with today's vehicles and fuels. At these cost levels, the incentives required to bring about their introduction in significant numbers almost certainly is beyond governments' ability to sustain financially."[14]

- In short, while there are useful gains that can be made through technical improvements in the near term, and the opportunity to influence demand for transportation (and the choice of modes) by pricing and regulatory measures, the sheer scale of the challenge leads one to the conclusion that, once again, publicly-funded R&D has an important role to play in trying to bring transport fuels based on renewable energy forward. If there is an obvious overlap of priorities with the electricity generation sector it is in the desirability of tapping solar radiation – it's scale and density make it a most desirable source of electricity which, if produced cheaply enough could bring hydrogen from water through electrolysis within reach. It is the 'ifs' in the sentence on which you should primarily focus your attention.

- I did not set out to write a policy speech – and there may be more than a few of you here wondering what on earth a former Environment Minister is doing talking to a room full of planners and lawyers about the technical possibilities of extracting our most significant energy needs from renewable sources. Here's why:

- Many of you in your professional lives run up against claims about the benefits and negative impacts of competing energy sources. Many of you have to think about alternatives and get some feeling for what is likely over different timescales. And those in the policy community dealing with an issue like climate change have to decide where they should try to make progress locally or nationally bearing in mind that the problem is global and the development of new technologies will unroll globally on different timescales.

- But the big picture is rarely spelt out. And it is a very complex picture. Now one way people react to complexity is by boiling things down to a few very simple propositions which provide comfort and, let's be honest, a way of out of having to think too hard in the face of that complexity. I don't criticise that approach – it's the way most of us cope with information overload. But it's important to challenge simple propositions from time to time.

- On the issue of energy supplies and their relationship to the issue of greenhouse gas emissions, I frequently encounter two simple propositions. One is that renewables will take care of the problem; the other is that there must be a big technological breakthrough round the corner. Sometimes they're held by the same people, sometimes not.

- My assessment, for what it's worth, is that the 'big picture' is currently telling us this:

  - For practical purposes there is no shortage of fossil fuels (although I accept that this is contentious in some quarters);

  - Renewables are a valuable source of energy if reliance on fossil fuels with their accompanying emissions is to be reduced. They do not, however, provide anything like a complete answer within a 30 year time-scale or longer. Continued fossil fuel use is inevitable – the challenge is to access the least carbon-intensive sources and use them as efficiently as possible

  - The contribution renewables can make varies significantly on a regional basis;

  - While formidable technical barriers stand in the way of improved performance by all technologies using renewable energy (other than hydro), electricity generation offers a wider variety of implementable options in the short to medium term. If governments were to collaborate on very long-term R&D at the global level, solar power options probably justify the biggest investments;

  - Fossil fuels are likely to retain their dominance in transport where the entire world economy has been engineered around liquid fossil fuel;

  - The ability of renewables to help reduce fossil fuel use in the transport sector in the current generation is very low and likely to remain that way for at least 20 – 30 years;

  - Anyone wanting to make an early, serious dent in transport emissions would be looking at regulatory and/or price constraints that make already commercial hybrid-electric vehicles even more attractive. They would also be looking to change the direction towards ever larger, heavier vehicles that have in recent years gobbled any efficiency gains. Compared with steps like these, the impact of urban design constraints seems negligible;

  - Governments wishing to shift the trajectory of emissions growth will need to supplement any market place incentives and R&D initiatives designed to break the fossil fuel technology lock-in with equal emphasis on energy efficiency. This potential is probably much cheaper to realise especially when there is no renewable silver bullet waiting in the wings at this point;

- The conclusions for New Zealand I leave you to draw. Clearly there are good prospects for additional electricity generated from renewables especially if people are prepared to weigh greenhouse gases equally in the scales with much more visible environmental impacts. Equally clearly, many of the technical breakthroughs needed to enable us to rely much more on renewable energy sources are likely to come from abroad – particularly improved means of generating electricity from solar radiation and the fuels and power trains needed for clean transport systems. Some of those technologies – such as hybrid-electric vehicles particularly for urban use – are already available. The speed of their market penetration will depend in part on regulatory standards.

- Although energy produced from renewable sources will have a regional flavour, the R&D challenges – like the environmental risks we face - are global. For that reason, there are strong reasons for small countries to stay closely engaged with international efforts to seek technical solutions.

- This has been a speech full of facts. I've tried to be as accurate as I can. But the thing which really struck me in gathering the material together is how nebulous a lot of the estimates are. Despite all the talk about renewables, the IEA advises that there has not thus far been a systematic attempt to assess, country by country, renewable potentials. The figures I gave you for New Zealand put together by Professor Sims are the sort of numbers needed at the regional and global level. This is the base information on which any debate about the potential contribution of renewables should rest. In the meantime, I hope I've given a glimpse of how interesting and complex this subject is so that next time someone blandly promotes or discredits renewables you'll be in a position to note that it's a bit more complicated than they might suppose!

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[1] Valuable comments on this paper from Ralph Sims and Vaclav Smil are gratefully acknowledged. All errors and omissions are the responsibility of the author alone.
[2] These broad, order-of-magnitude numbers are based on Smil, V., *Energy at the Crossroads*, MIT Press (2004); see in particular, pp. 239-316.
[3] Ibid, p. 242
[4] Ibid, p. 58
[5] IEA, *Key World Energy Statistics 2003*, p.46
[6] Smil, (2004), p. 247
[7] Ibid. p. 258
[8] Ibid. pp268-269
[9] Ibid. p. 259
[10] Ibid. p. 275
[11] IEA, *Key World Energy Statistics 2003*), p.6; the figure for IEA countries representing the developed world is just 5% (see *Renewable Energy – Market & Policy Trends in IEA Countries* (2004), p. 43).

[12] http://www.oecd.org/dataoecd/45/60/33764496.pdf

[13] World Business Council for Sustainable Development, *Mobility 2030: Meeting the Challenges to Sustainability* (2004). All pages references are to the report which can be found at: http://www.wbcsd.org/web/mobilitypubs.htm

[14] Ibid, p. 109

Table 1: Global Renewable Energy Potentials

Renewable fluxes	Potentially available PJ/year	Currently appropriated	Upside	Ability to make a significant dent in global ghg emissions
Solar	682 million	> 0.001%[1]	Significant	Significant
Wind	3.8 million[2]	>0.001%[3]	Significant	Small
Net Terrestrial Photosynthesis	1.8 million[4]	40%[5]	Small	Small
River flows	35,000[6]	30%[7]	Small-Medium	Small
Ocean Currents	?	nil	?	Insignificant
Geothermal	4,400[8]	5%[9]	Small	Small
Tidal Friction	100,000[10]	nil[11]	?	Insignificant
Fossil	320,000			

[1] IEA publication, Renewables Information 2004.

[2] Personal comment Prof. Smil.

[3] IEA publication, Renewables Information 2004.

[4] Smil, Vaclav. 2003. Energy at the Crossroads, page 264.

[5] Ibid, page 265-266.

[6] Ibid, page 247.

[7] Ibid, page 247.

[8] Ibid, page 291.

[9] Personal comment Prof. Smil.

[10] Smil, Vaclav. 2003. Energy at the Crossroads, page 293.

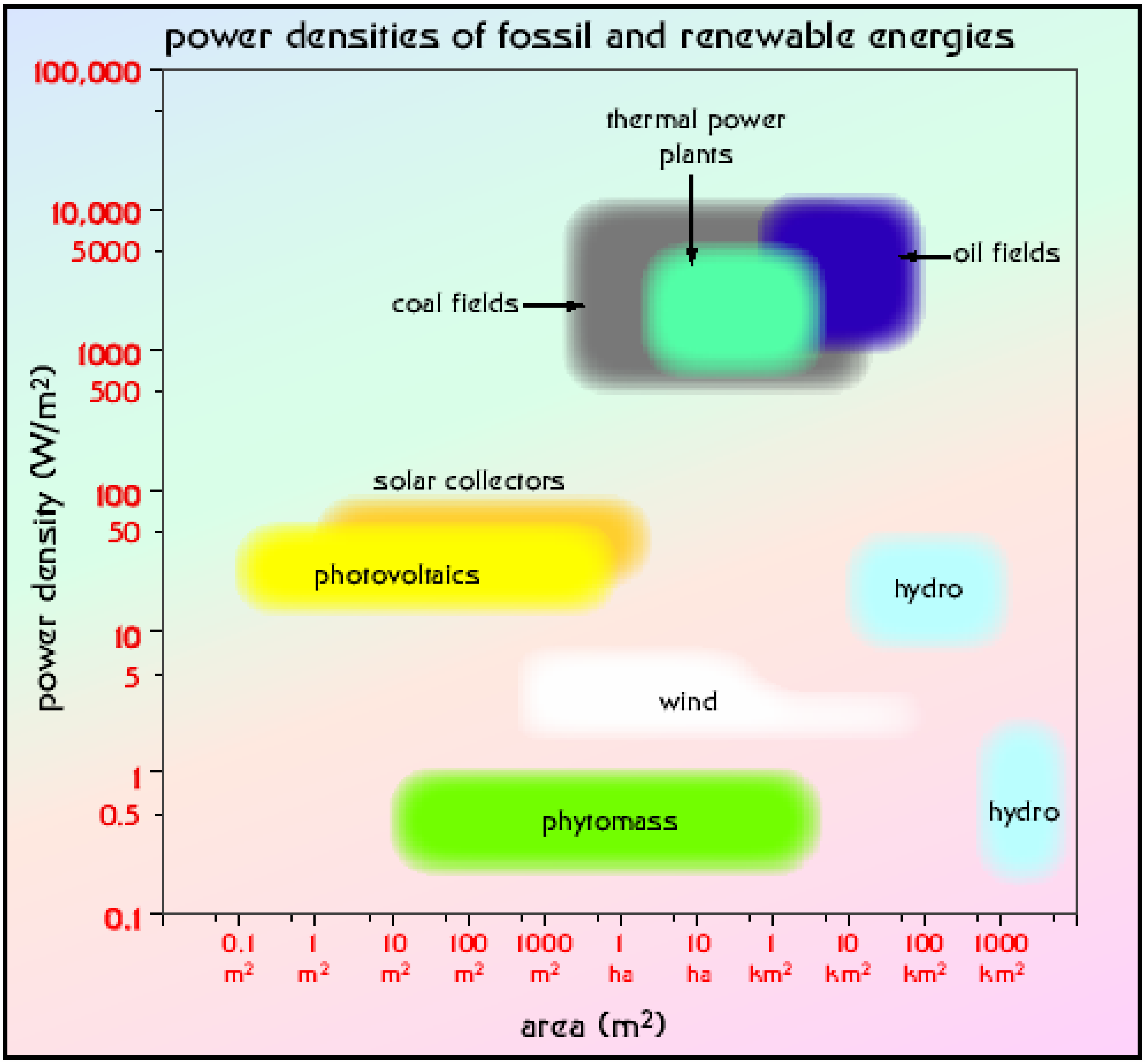
[11] Ibid, page 293.

Table 2: Summary of New Zealand Renewable Energy Potentials

	Reserves	Theoretical	Technical	Economic	Market
	PJ Total	PJ/year	PJ/year	PJ/year	PJ/year
Solar		1,562,000	234,000	22	0.19
Wind		?	4,500	34	2.3
Biomass		241,000	3,200	347	36.0
Hydro		915	365	122	89.0
Geothermal		547	82	30	21.8
Wave		?	?	0	0
Tidal		12	3	0	0
Ocean		?	?	0	0
Coal	300,000				64
Oil	1,000				65
Gas	2,000				230

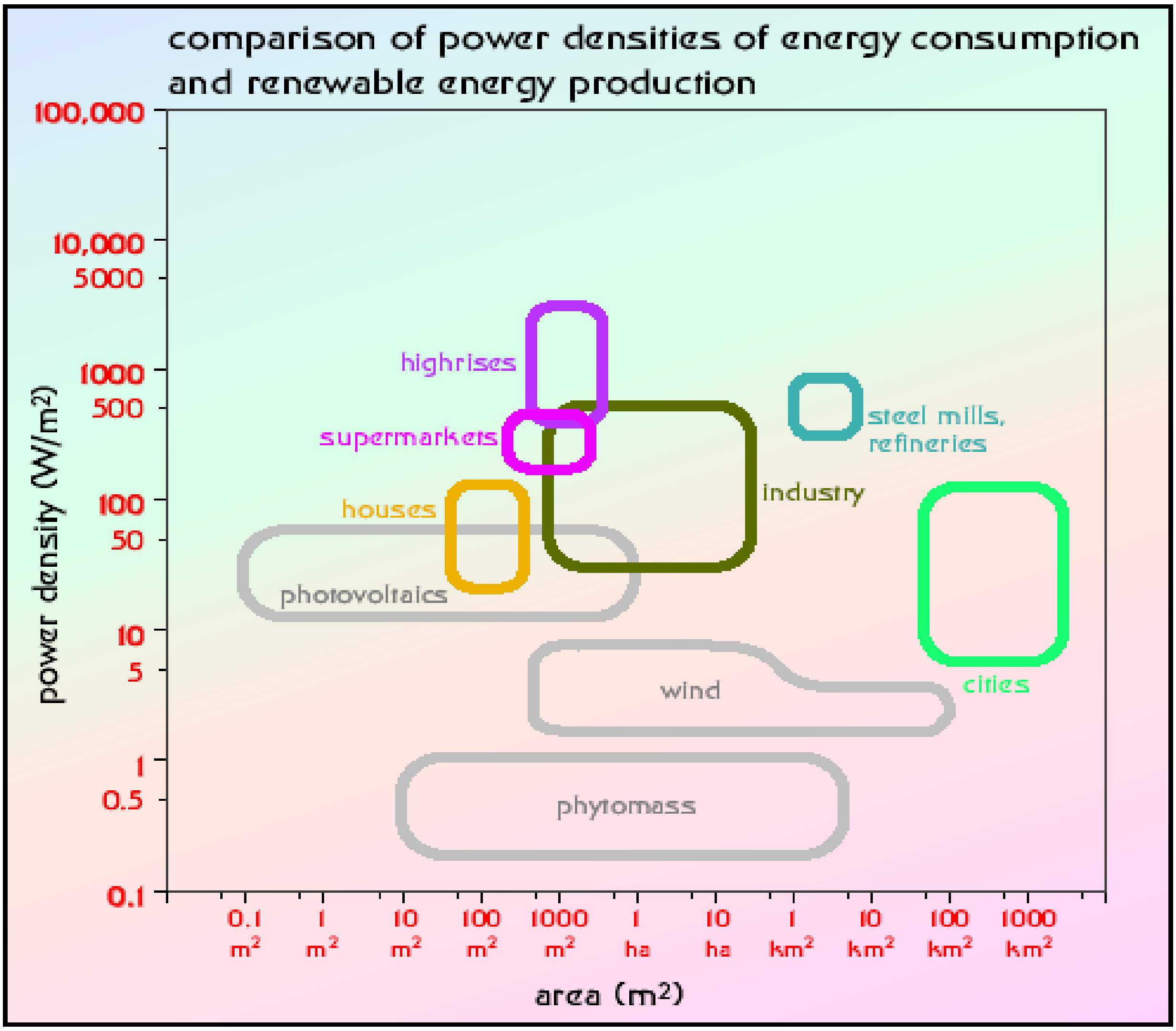
Source: Professor Ralph Sims, Massey University, New Zealand

Figure 1: Power densities of fossil and renewable energies



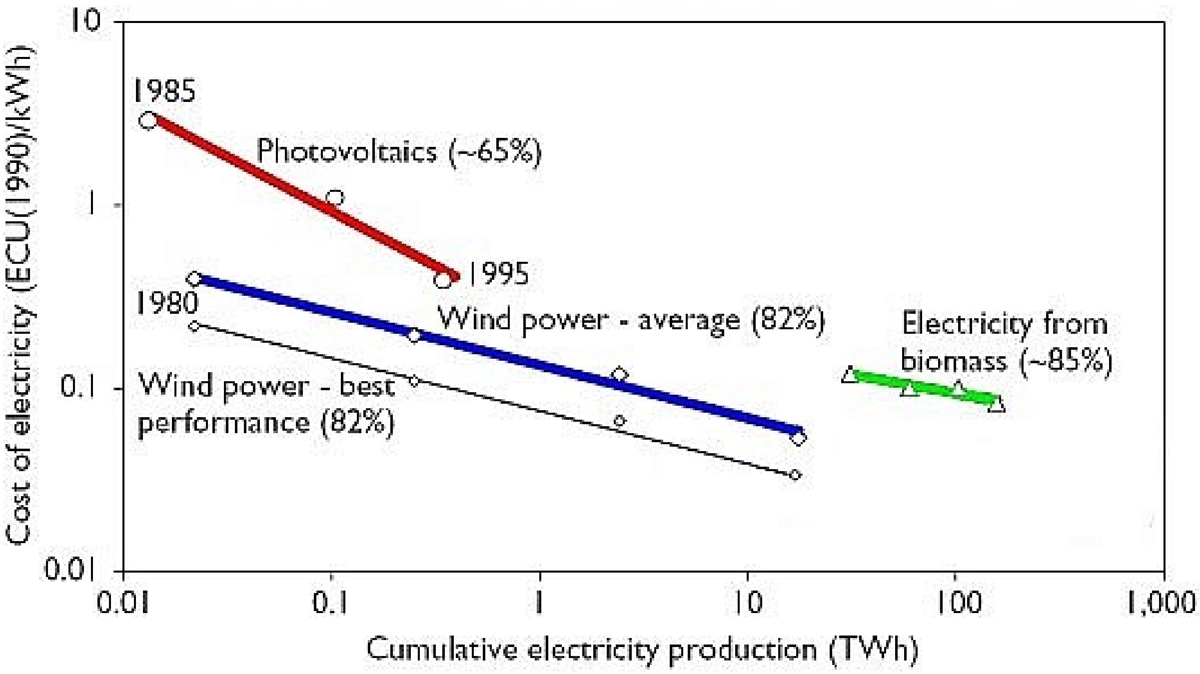
Based on Smil, *Energy at the Crossroads* (2004), p 242

Figure 2: Comparison of power densities of energy consumption and renewable energy production



Based on Smil, *Energy at the Crossroads* (2004), p.243

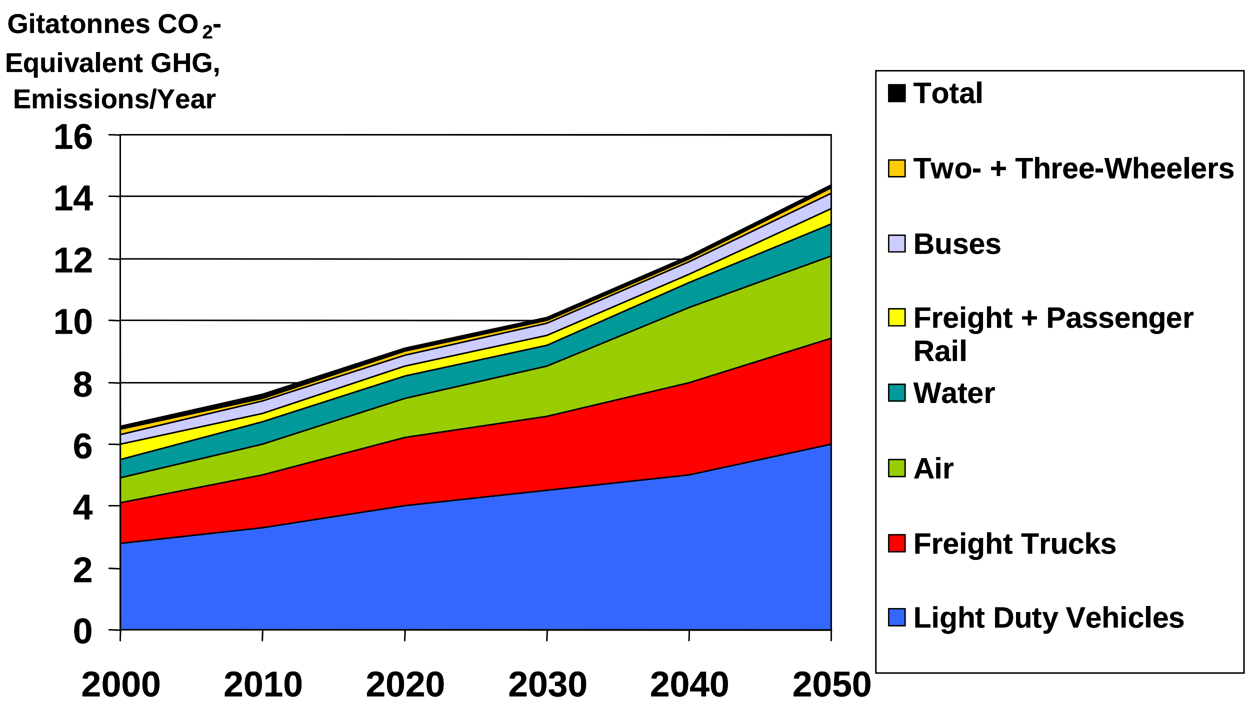
Figure 3: Cost reductions with increasing deployment



Percentage reduction (%) for each doubling of deployment

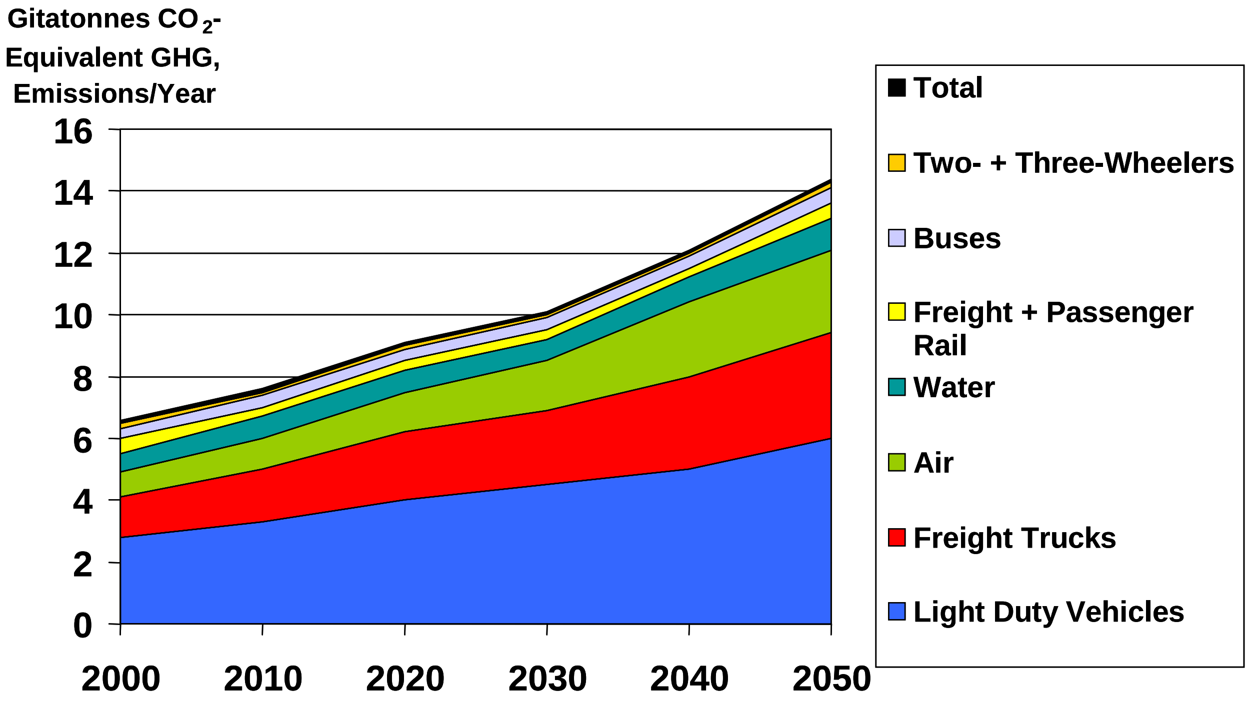
Source: International Energy Agency (2000).

Figure 4: Freight transport activity by region



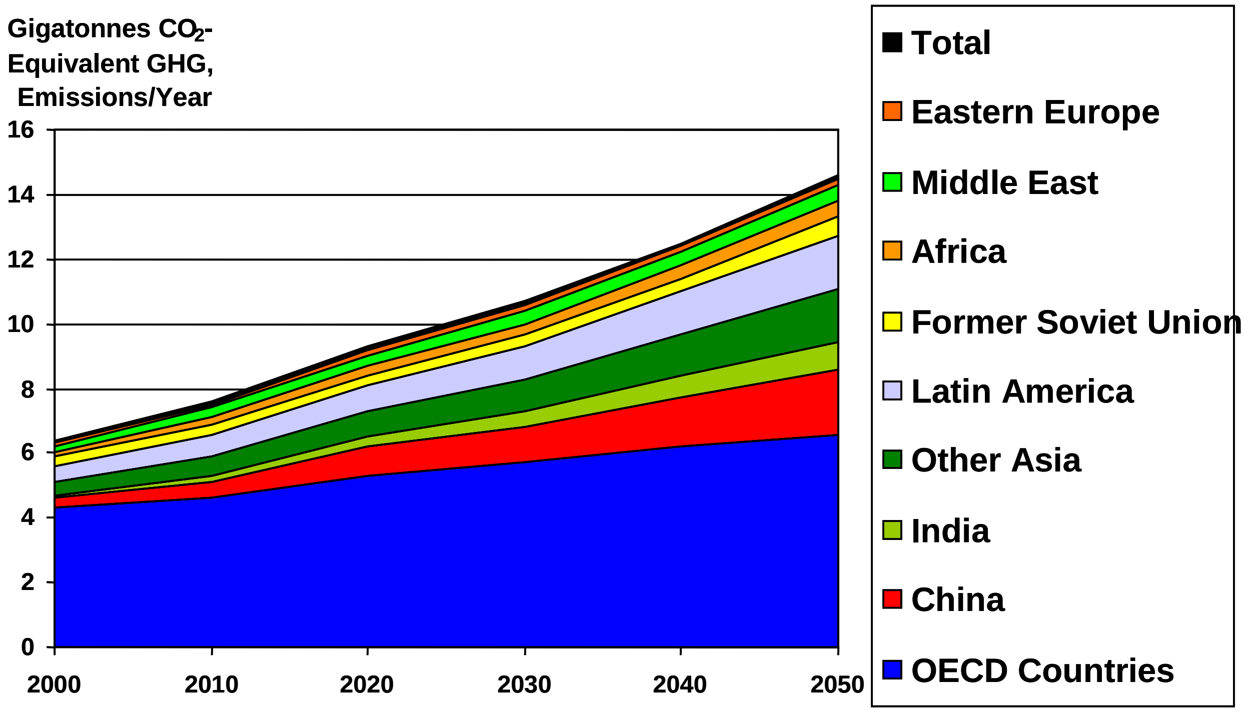
***Mobility 2030*, p.32**

Figure 5: Transport-related Well-to-Wheels CO2 emissions by mode



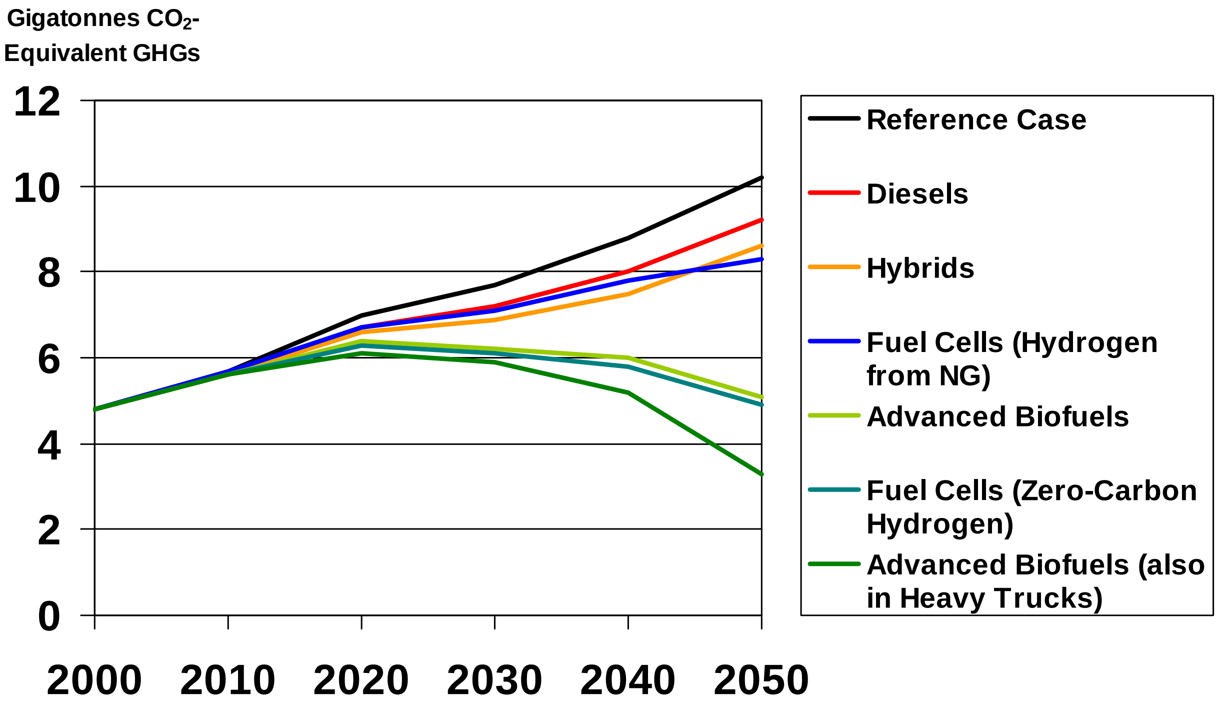
Mobility 2030, **p.37**

Figure 6: Transport-related Well-To-Wheels CO2 emissions by region



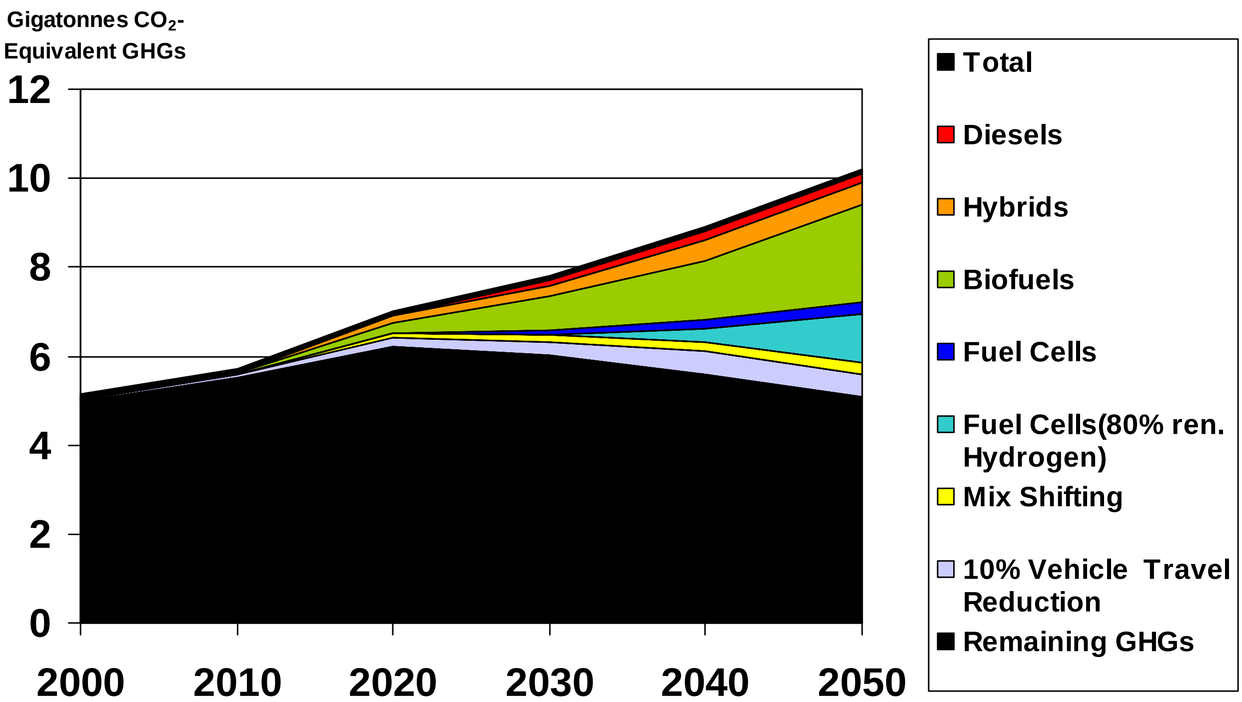
Mobility 2030**, p.37**

Figure 7: Hypothetical potential of individual technologies to lower road transport Well-to/Wheels CO2 emissions relative to the reference case



***Mobility 2030*, p.113**

Figure 8: Combined technology case



***Mobility 2030*, p.117**