OFFICE OF THE PRIME MINISTER'S CHIEF SCIENCE ADVISOR

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Visioneering a Future

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If you had been able to ask the founders of the Institute 100 years ago to predict today's technology landscape, there would have been little or no correlation between what those men would have predicted and what has happened in a century of escalating and disruptive technology. Similarly, I suspect that if in 100 years' time, your grand-daughters, the engineers of tomorrow, were to look back at the bicentennial of IPENZ, they too would find little or no correlation between our technological predictions and reality.

So despite the topic of this address, I am not about to embark on what would inevitably be a totally unrealistic view of the next 100 years. Indeed futurism when it comes to science and technology is best left to the science fiction writers. Certainly we can look ahead a few years with some knowledge of what is already happening in laboratories and universities, but to look any further ahead is really a matter for our imagination. Indeed as that great philosopher of baseball Yogi Berra once said "its tough to make predictions, especially about the future". So on the specific examples I will give, ignore everything I am about to say, but on the issues these example raise please reflect deeply.

We know we certainly face a world with at least 10 billion people – that is 30% more people than now live on the planet, many with a justified entitlement for better quality of life and longer lives, all with concerns over energy, water and food security and climate change; and facing issues of greater urbanization. There will be ramifications for the ways we interact with each other, how we live our longer lives, how we deal with ill-health, how we fill our leisure time, family structure, what provides life satisfaction, and immense pressures on our environment, while at the same time demands will grow for economic growth to meet the expectations of the planet's citizens. We face a future that is information overloaded and privacy limited and where the formation of wealth in many countries will move dramatically from commodities and manufacturing to knowledge generation. And this is what we can see and yet there are many disruptive technologies ahead that we cannot yet envisage. The consequences will be seen at every level from familial to community, to national to planetary and will have immense personal, societal and geopolitical implications.

And here is the paradox of science, engineering and technology. In one sense it has been a series of technological advances over the past 10000 years and particularly the last 300 years that are the ultimate reasons we face these pressures: it is the uniqueness of our species to continue to develop technologies, to then learn rapidly from each other and spread and modify these technologies through the processes of cultural evolution. The feed-forward loops inherent in these processes, and in particular developments in nutrition, industrial agriculture, public health and public health engineering, have led to the exponential growth in population, which is the ultimate driver of many of these pressures.

Inherent in this has been the development of transportation and communication technologies - leading to the very connected world that we now live in and this in turn has led to an exponential feed-forward system in which technologies compound on top of each other often with quite disruptive implications.

It was the industrial revolution and the enlightenment that led to both population growth and created our dependence on fossil fuels and that, along with agricultural expansion resulting in deforestation, has led to the rapid rise in greenhouse gases that drives anthropogenic climate change. It was the development of industrial manufacturing that led to the growth of cities followed by the development of services industries – themselves fueled in the 20th century by a large number of technologies – especially in communications and computing. And cities themselves depend on an enormous range of technologies – in utilities and transport - to function. It was the processes of food technology and agricultural industrialisation that have led to our modern problems of obesity, diabetes and heart disease.

And yet we know we cannot go backwards – these are all irreversible technologies. Seven billion people will not return to a Paleolithic existence: indeed it is our human nature not to do so. After all, these technologies are all manifestations of the basic human drive to know more, to live longer, to live better. And if we look at all the so-called grand societal challenges we know that science and technology are going to be critical to their resolution - indeed there is no challenge ahead of us where science and engineering are not central to their resolution. Be it clean energy and more energy, more food, clean water, be it living in mega-cities, be it sustaining our environment, be it living healthier but longer lives. And as we live in more dense communities of very different nature the importance of the social sciences will become increasingly important.

But as my remarks have already implied, the relationship between science, technology and society is not simple. Society has a right and indeed the expectation to be a more overt partner in how technologies develop and are applied. And there are immense challenges in that simple statement – we may worry more, about the government when it comes to big data and privacy, but Google, Facebook and Twitter know far more about us and they use it. In a world that is globalised by technology, how are we to sustain balance in how technologies are developed in the private sector and the public interest? We have seen how difficult it is to regulate transnationally across many domains – for example in areas such as taxation.

Another paradox is that some technologies develop in a way that is overtly disruptive and yet many equally disruptive technologies emerge without much reflection or awareness – these may have evolved via incremental progress but even so the net effect is disruptive. Let me give two obvious examples which reflect these differences in reverse order. The first is the internet – this gradually emerged without much public reflection; yet its impact on society is complex and universal but still poorly understood – we all take advantage of it, it has led to advances in all spheres of activity and it has changed people's access to information. But it has also led to cyber-bullying, concerns over loss of control of personal information particularly in the private sector, a total change in concepts of personal space particularly for young people and overall a giant loss of privacy, fundamental ways in which people interact with and communicate with each other. We do not really know how to regulate it and indeed whether it can be regulated.

By contrast consider the use of genetically modified organisms for food production: a technology that emerged more acutely, a technology that was quickly regulated, and in doing so created an unusual situation where it was the technology itself rather than its use which was regulated in some countries such as NZ.

Here are two disruptive technologies: one crept up on the public and was rapidly accepted but is overtly disruptive in multiple ways and the other where the social license to use it was much more variable around the world and remains so some 20 years on. Now these are not the only differences between these two technologies – one involves living matter directly, the other only indirectly although studies on brain development and function in the digital age might suggest bigger effects than many would realise. One involves widespread advantage, the other may or may not and so forth. I shall return to these differences later.

But I have spent time on all of this because without being too futuristic it is clear that many potentially valuable technologies are emerging that have enormous ethical, moral and societal implications. And because of this they will or should fundamentally change the way scientists, engineers and technologists operate.

So let me expand the discussion by considering examples that we know are in our not too distant future. I have borrowed some examples of these from an essay by Michio Kaku in the NY times from 2013 – he interviewed over 300 scientists in coming up with a list that I have freely modified.

Rather than cover the gamut of possibilities let me just focus on a few that highlight some of the challenges ahead for the engineering profession.

Driverless cars are almost with us now - the arguments for them seem obvious to the engineers developing them– remove human factors and perhaps we will all be safer. From the technology point of view it all seems simple but as the internet of things grows, that is as devices become more connected into the internet, and pilotless cars will have to be part of that internet of things just to know where they are, how is cyber-security to be maintained because without that how will passenger safety be maintained. How do we interface human driven vehicles with vehicular robots? How comfortable will parents be putting their children into a driverless bus to go to school?

And what of all these pilotless drones - beyond their obvious military applications as civilian use expands, privacy concerns emerge – the press are already using them as an advanced form of paparazzi. It sounds trivial to ask such questions but perhaps they are not so trite. Privacy is a concept of western society that seems to be rapidly eroded by technology. And over time how will we manage and regulate airspace – certainly it can be done but multiple complexities of control, safety and integrity emerge. Can security of these systems be maintained in a world of cybercrime and cyberterrorism.

I focus on loss of privacy because I think that loss is something that we are not very conscious of. Western society has longer valued privacy. We get outraged when the

State is perceived to overstep some boundaries in trying to ensure our public safety – but think of the information the private sector has on us – through supermarket checkouts, amazon, or Facebook or google. As more and more of what we do is stored in the cloud it will be more and more accessible one way or another. We seem to have passively accepted the private sector having all this information. And look at some of the consequences – young people share intimacies on the web we of an older generation might never share. We get inundated with very clever advertising in response to our internet searches.

Is this fundamental shift in the way we live our private lives going to alter the way we live with each other. We already know the net is changing the way we learn and communicate with each other. How many office wars would have never occurred if a disagreement had been dealt with face to face rather than by email? I am emphasising these examples of what is on us already, not to be a luddite, that would be like King Canute, but to point out what is the key theme of my talk – namely technology is not isolated from society. While medicine has particularly since the second world war had to think about how it engages with society, many other domains of science and technology have done so poorly; and when they have done so it has largely been in a patronising manner. This cannot be the way ahead.

Let me continue

Biotechnology and medical technology have had enormous impact on health over the last 30 years since the first recombinant hormones were made in the 1980s. Insulin for diabetes, erythropoietin for renal failure, many vaccines, some cancer drugs all are made by this technology. But this is only the start – while I am sceptical of the use of genomics in isolation, when combined with other forms of molecular analysis, medicine may become increasingly individualised. The potential for sensors to pick up the most early signs of disease is almost on us, Kaku suggests DNA sensors in the toilet pan will be used to find precancerous lesions, but the implications of demand on over-burdened health systems in an increasingly demanding population and the ethical issues of very early diagnosis of diseases of aging are profound.

But even bigger issues emerge with the rise of tissue engineering, artificial organs, stem cell derived organ replacement and bioimplants – we already have simple versions of the latter used for heart pacemakers and an emerging number of brain stimulators are being implanted for epilepsy. I have seen telemetry from animals' brains being used to control motor devices and there is inherently no reason why this will not happen in humans – indeed I suspect it is very soon upon us so as to give paralysed people more independence. But think out 50 years - where will telemetry from the brain stop – how will humans brains be connected to the internet – and for certain it will not always be one way – that is from the human to the robot – what will be the impact of possible control in the reverse direction especially when that robot is not isolated from the cloud. One does not need to be too futuristic to see the possibilities, not all for the good. Does memory implantation replace learning, are emotions no longer ones own but those of the net. Again I am not trying to create fears about big brother or argue for a luddite position but trying to point out that the issues of technology development extend far beyond the engineer and the scientist and must engage with the humanities, the social sciences and indeed the whole of society.

The history of mankind is basically been one of balancing the good side of innovation with the bad that comes with it – the spear and the gun allowed food to be caught but it allowed warfare to be more intense. The discovery of radioactivity brought medical advances and it brought fear of mutual assured destruction, the motor-car brought ease of transport but also pollution and drunk drivers. As innovation in technology becomes more rapid, the ability of society to adjust and understand becomes more limited.

The 1970s brought the first efforts at genetic modification – the insertion of genes into bacteria. That and the reverse methodology of knocking genes out of the DNA has been an enormous boon to biological sciences. Our understanding of evolution, the development of many drugs and diagnostics, the pathogenesis of many diseases is better understood. Without molecular biology, the scourge of HIV and AIDS would have been so much worse – it was this science that allowed the antiretroviral drugs to be developed. But genetic modification was only the start of a much broader range of molecular technologies.

The production of genetically modified foods is one such example and we need to reflect on why that has been so controversial. Is it because of the alleged lack of safety – no – these are perhaps the most studied foods in the world for their safety. The issues are not primarily technological, they are philosophical – this makes them no less valid. Concerns over the control of the food supply by multinationals was a significant component especially initially, but even more so has been attitudes to what is natural and what is not. Let me hasten to add, I understand and fully accept the right of a society like NZ to set out a position based on values but in doing so it highlights an issue, also seen in the climate change debate, that sometimes debates over science and technology can be used to obfuscate a needed and proper debate which is not about the science but about societal values.

But what will happen over time when engineering can be used to change the properties of an organism without changing its genes through changing regulatory processes – this is on us now – such techniques exist – how will society treat this – how can it be regulated, how can it be detected. And beyond this simple example synthetic biology is now with us – creating almost entirely artificial bacteria to do things like clean up oil slicks or clean gas stacks of CO2. The capacity to do this exists - technology merely has to advance to make it economically feasible – how again will one regulate such technologies for good and in a way that is acceptable to different societies – bacteria know no national boundaries.

And thinking more about the future of food technology: we have already seen artificial meat made by cell culture. In time milk could be also. An increasing number of food ingredients are made in algal cultures. Food quality can be affected by structural components. Could 3D printing be used to create artificial foods of better quality? All this is feasible and there may be dramatic changes over time in the source of our foods. Many of these techniques would of course potentially affect our economy but enhance our environment. But how will they be accepted.

There is a sense that what we see as natural is what we grew up with, so over generations what is now not acceptable may change. Indeed societal values can change rapidly – look for example at a change within two generations over the acceptability by societies of abortion. Again we know little about how technologies are perceived over time and technological developments cannot move forward without good social science and understandings of how social license develops.

Robotics is developing fast – they have been used in heavy manufacturing for years and now are being used to help disabled people maintain independent living. Many homes now have robotic vacuum cleaners. But as artificial intelligence algorithms develop, the range of possibilities grows: the potential link to the internet of things and the internet of minds offers hopes in areas such as aging care and so forth. But again what are the ethics of interactions between humans and machines – we can, I hope, be pretty certain machines will not exercise creativity or emotions – these will for the foreseeable future remain human properties but linkage to the cloud in both directions conjures up all sorts of possibilities both good and more concerning.

I could go on – let me just give two more examples.

Climate change is with us and geopolitical considerations mean that sadly we must not only deal with mitigation but also with adaptive responses. Because within 50 years there will be major changes in where the rain falls and when it falls, this means that in NZ this will require large scale irrigation to shift rainfall from where it happens to where we grow crops and grass. Either that will mean possibly the largest civil engineering works we have ever considered or a total change in our economy to dry-land agriculture. But beyond our shores if emissions are not controlled and if the scale of climate change is at the upper end of the range of models, the planet may face harder choices – will carbon capture techniques work at scale or will geo-engineering be needed, and if the latter how will international consensus to do so be reached. Now I am getting futuristic and out of my comfort zone but the engineering world needs to engage in thinking about these possible scenarios.

As engineering continues to innovate, the potential for resource extraction from even more difficult parts of the planet grows. It may be deeper, it may be in more extreme climates, it may be under the sea – sea bed mining is already a reality. And as the demand for more resource extraction grows so will the investment in such extractive technologies. But as that grows so will concerns for our planetary health, and here we come to the fundamental dilemma for all western societies – how to balance growing economic and resource needs and public expectations against the need to better protect the planet. This equation is one that governments of every ideological persuasion have to deal with and the challenge will get harder and harder at least at a global level. And here we come to the issue of risk identification, management and understanding and the engineering profession has an enormous and somewhat unmet responsibility in this regard.

Each of these vignettes is somewhat speculative but many are effectively almost now realities. But every one of these technologies has not only the potential to greatly benefit society but also carries enormous ethical and societal dimensions. Two related concepts emerge which the engineering profession needs to give much more attention to: that of social license and that of public reason.

Different societies have different ways of reaching an effective consensus – this is the concept of public reason. Thus the way that (say) Germany or the USA or New Zealand establish their position on issues such as social welfare or nuclear power involves very different engagement between civil society, policy makers, academies and the politician. And through these processes of public reason, technologies can or will not be given social license. It is not simply a matter of the ballot box: rather different societies that superficially seem the same can reach very different positions on matters such as stem cell biology, abortion, water fluoridation, genetically modified foods, nuclear power, the use of cannabis and indoor farming.

My examples were intended to show how social license will be needed for many technologies before they can be healthily employed and often this will mean regulation – for we regulate many technologies now. We regulate medicines, we regulate mining, we regulate aircraft, we regulate motor vehicles in many ways, we cannot take genetic modification in NZ out of the lab except with enormous complexity, we will not develop nuclear power and so on.

But some technologies which we would like to regulate we struggle to do so. Think of the abuse of the internet – pornography, cyber-bullying, industrial espionage, and so forth. Engineers like scientists musty engage better in societal debates about the use and limits of technologies they are largely responsible for imagining and developing.

And underlying much of this discourse is the issue of the understanding of risk.

The challenge is that 'risk' is a word with very different meanings and is perceived in very different ways in different contexts. Understanding the interaction between hazard, exposure and risk is not easy. To the statistician or engineer, risk is a mathematical calculation of probabilities, although the assumptions that might underlie those calculations can very enormously. Those calculations are then used to attempt to objectively decide on a particular course of action. To the politician risk might be personalised to the electoral consequences of a particular decision. But to most people risk is a vaguely defined concept by which people make largely visceral decisions to do something or not to do something. At times some form of reflective calculation is made consciously or unconsciously but the calculus used is usually very different to that of the engineer. The confusion of these meanings is inevitable given the large emotional content in how most people interpret the word. But it is the latter meanings that will largely determine whether social license is given.

When we make an estimate of risk, in most cases we are considering the consequences of making one decision or another within a range of options. Implicit in this calculus is the recognition that in the types of cases we are considering little is absolute, that is we have to think probabilistically, and that every decision has some probability of either positive and/or negative consequences. When these matters are trivial or the probabilities are close to absolute certainty, decision making is relatively simple. But most of the matters of high public concern are not trivial – should a road be improved to reduce the risk of car crashes – there are consequences of doing so – there are less funds available to do something else.

And this brings us to the second and related concept when risks are considered – that of tradeoffs. Any decision made in a complex area involves tradeoffs and these tradeoffs are often not in the same domain and are not always obvious. Yet when we decide to limit or use a new technology we are undertaking some form of risk assessment. All innovation requires by definition some risk – otherwise extreme precaution is a recipe for total inaction. Sometimes the concept of precaution has been misused by advocates for particular positions – the precautionary principle is not about absolute inaction, rather it is about positive action to manage risks until more is known, and risk management strategies can then be revised allowing society either to further open up use of a technology or limit it further.

The consequence of the magnificence of the human condition is that different individuals have different perceptions of risk and value in the tradeoffs that need to be made – when it comes to technologies the wider the understanding of them, the more there is a proper dialogue between scientist or engineer with the public, the healthier will be our choices into the future. Such a dialogue is not easy especially when the issues have a high values component – indeed in NZ we struggle to have true dialogues in such areas – this may be a characteristic of our individualistic nature. I personally think it is healthier if academies such as IPENZ and the Royal Society of NZ take a role in transmitting knowledge about the issues rather than advocating for any particular position. Ultimately it is for society to decide on any technology, its use and limitations; our role is to inform them and assist their consideration. I see my role as an honest broker in such dialogues; so too should be the academies. Achieving a better understanding of what precaution, risk identification and management really mean is essential: otherwise we face paralysis in the face of many opportunities and challenges.

Technologies do have their upsides and their downsides and need to be managed – it is finding a balance acceptable to a society that is key - be it in earthquake engineering or in food technology. This is our challenge and will be even more so into the future. A luddite approach is not realistic, new technologies will be continually emerging, total precaution is unrealistic because that means no new technologies.

Engineering is sometimes portrayed as a mechanical science devoid of having to consider human values. It is anything but. My address has been a plea for engineering to better show its human side, to embrace the social sciences as a collegial science. Engineers need to come out more from behind their computers and machines and tell their human stories, engage with the public, explain technologies, explain their benefits and risk. Only then will we take the best that you can and will provide, and use it well to improve all our futures.