OFFICE OF THE PRIME MINISTER'S CHIEF SCIENCE ADVISOR

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New life science technologies, social license and social consensus[1]

Royal Society Te Aparangi 150th anniversary Regional lecture; Te Papa

Sir Peter Gluckman

Let me start by congratulating the Royal Society Te Aparangi on its sesquicentennial – this is my 30th year as a fellow. I am a member of the Board of Te Papa and one of our goals is to encourage Te Papa to be a place for deep conversation on issues that are important but too often get drowned out in sound bites, rhetoric and polemic. I am also a member of the OECD Advisory Group on digital futures. And in those discussions, we have repeatedly returned to the question of the social acceptance or otherwise of new technologies: whether we're talking about the digital, engineering or biological technologies.

Most technologies invite societal debate – sometimes this is proactive, as in the case of reproductive technologies, sometimes it is reactive as is now happening over digital technologies. And that societal debate can be manifested in either reactive or pre-emptive regulation, and both can have their problems.

I have spent most of the last eight years being a broker between the science community and the policy community. And these are very different cultures. Policy-making is largely about making choices between different options and those options affect different stakeholders in very many different ways. All governments have the challenge of choosing between the impact on different stakeholders for good or bad when they make policy choices. And they are torn between managing short-term electoral risk and promoting longer- term strategy.

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[1] *This speech has large elements taken from my addresses to the 17th International Biotechnology Symposium in Melbourne October 2017 and to Lincoln University as its State of the Enviornment AnnualLlecture in July 2017.*

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Importantly science does not make the policy, it can only inform policy. Democracy works off decision-making informed by many other values-laden considerations: public opinion, political ideology, electoral contract, fiscal considerations, diplomatic considerations, etc. Policy making is not the neat cycle it is sometimes suggested to be, rather it is a messy process involving formal and informal actors, and politicians tend only to act when a feasible solution presents itself. They cannot be expected to be scientific referees.

But we also cannot talk about the interaction between science and policy unless we also think about the interaction between science and society. As technologies of many types will play a greater part in our future, we will need the policy community and society via the democratic process to be continually engaged with the scientific discussion. And this will not happen if complex discussions are reduced to political point scoring, 140 character tweets or 10 second sound bites on television. Much more mature and multidimensional discussion will be needed but this is increasingly difficult with the echo chamber of social media, and the decline in trust in institutions, in the media and experts. The post-expert and post-truth[2] world will make many important decisions that much harder and could threaten the nature of democracy itself. Science has an important role in being a bastion against that threat.

To get there we will have to look again how we better engage between science and the rest of society. It is not as in 1942 when Robert Merton, the sociologist of science, described scientists as priests standing on an altar revealing truths to an ignorant society; rather today science is deeply embedded within society – a society that still is generally supportive of the scientific effort and which is increasingly empowered in its decision making. We make a big mistake if we approach the rest of society with the deficit model in mind; yet that is still how much scientific communication occurs.

People have very different and deeply held worldviews reflecting their culture, tradition, past experience, persona and context. We need to understand that science alone will not resolve different worldviews; rather it can actually make them more divergent as we have seen in the case of climate change. People interpret data and evidence through lenses shaped by their cognitive biases.

[2] 'Post-truth' relates to the acceptance of arguments based on beliefs and emotions rather than facts

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Ultimately the choice that society makes about any innovation is about perceptions of relative risk and of cost (and to whom) and benefit (and to whom). And while the pace of innovation is now much faster, it is nothing new. All said and done it is in our evolved capacities to innovate – to learn through cultural evolution. The progressive evolution of our cognitive and manual skills has meant that most human societies have been in a constant phase of innovation since we first emerged as a species. But the pace of innovation is now rising exponentially, and what is relatively new – perhaps since the middle of the 19th century – is the ability of democratic society to have some say in how technologies evolve, and how they are used and controlled.

Let's start by going back to perhaps the first real example of a contentious and complex interaction between biotechnology and society; the development of margarine. I am indebted for this story to the outstanding recent book by Callestous Juma; *Innovation and Its Enemies (Oxford 2016).* A quote from those times from the anti-margarine (dairy) lobby reads "as for butter vs margarine, I trust cows more than chemists." And, I think, you could think about echoes of that kind of comment in some of the debates that are continuing today about genetically modified foods.

Through much of 19th century the quality of dairy products was very unreliable and not industrially produced. In the 1860s in France there was concern about the weakness of their military personnel and it was considered to be the result of poor nutrition and inadequate energy intakes. So the French government had an innovation competition for a better form of nutrition for young males, and the result of that was the invention of margarine as an animal fat extract. And relatively soon after that American companies started to manufacture margarine from animal fat on an industrial scale. At that time the dairy industry in America was weak and disorganised and quality control was non-existent. The arrival of animal-fat based margarine was the impetus that led the dairy industry in the United States to organise, to coalesce and to create lobby groups. The dairy lobby started to provide and promote anti-margarine information and much of this information was based on fraudulent science, on bad science, and on post-truth claims about how poisonous animal fat-based margarine was. Lobbying of farm state politicians across the USA led to the imposition of all sorts of taxes, restrictions on the colour the margarine could be, composition labelling to try to discourage purchase, etc.

The anti-margarine advocates argued that this stuff was full of poisons alleging that it was made from rancid meat. The margarine makers responded with innovation; they

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found a way to hydrogenate vegetable fats, allowing the margarine manufacturers to move from animal fat to vegetable fat. The vegetable fat they originally used was coconut oil imported from the Philippines. This prompted a whole lot of new, spurious arguments to stop the importation of Philippine coconut oil. So the margarine manufacturers started to move to hydrogenating US based soya bean and cotton oils. Now the local politicians had cropping farmers who actually wanted margarine to succeed, and so did their senators, and the power of the dairy lobby started to fall away. Gradually the restrictions evaporated, but it wasn't until the 1970s that in many states margarine first became fully available, without any restrictions. It was only in 1972 that we stopped having to have a prescription to be able to get margarine in New Zealand. And the argument did not stop overnight. It continued with a more solid and new concern about trans-fats, but these were then removed from margarine and it is generally accepted now that lower-fat margarines are for the most part healthy products.

This story has contemporary echoes: strong commercial interests in place, impacts on society that led to the organisation of new industry lobbies and political alliances, false science claims put forward, new innovation to overcome the objections which in turn led to new objections. Alternate facts at work. Restrictions were imposed, and it took approximately 100 years for social licence to be achieved as the political and social dynamics changed and the alleged risks fell away.

So what is social licence? Social licence, or better social consensus, was a concept originally developed to allow industries with manufacturing plants to have on-going approval from the local community and other stakeholders. For instance this might relate to operating a chemical plant or a mine. But the concept has been now been more broadly adopted to include the acceptance of technological innovations by society. It is a complex topic involving different perceptions of risk and benefit, and different views of different stakeholders. It varies for different types of technology and is managed differently for different types of product. Depending on the technology and the societal response, it may involve regulators and formal processes, it engages politicians or it is driven by the market place.

There are many reasons why there are tensions about innovations. Underneath there is conflict that arises because fundamentally people are comfortable with what they've got, what they know, and generally they fear the unknown. This leads them to prefer what they have despite its limitations, to what might come. And there's always a

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tension in any society between the stability of what we know now and the novelty of the future and of new innovations.

It is of course exacerbated by many other issues; the positioning and power of incumbent technologies and the associated path dependencies, perceptions of risk, costs and benefits of new technology and who receives or bears them, differing world views and so forth. And there can be strong economic interests on either side of such debates. That partisan politics might aggravate such complex discussions is thus almost inevitable. Social licence in this broader context is about when the socio-political environment allows the technology to be used. Many factors affect technological social licence.

Central to technological acceptance, or not, is the relationship between science and society. There is the issue of the state of the evidence and the claims around it, and this can be the source of real or apparent debate. But underneath this you come down to a set of deeper issues; is there trust in the actors, is there trust in the science? We now hear a lot of the term 'post-trust' society: a key strategy for groups who take a strong position to undermine the credibility of those actors who take an alternate position.

Secondly, people have different worldviews and values and these are often in dispute: and science alone cannot not resolve such disputed values. Related to this is the issue of competition with incumbent technologies and, in general, if they involve different stakeholders to the new technology, the incumbents will react against it (the dairy farmers reacted against the margarine manufacturer).

In general people accept a new innovation more readily if they can see direct benefit from it, for instance the smartphone, and are less likely to accept a new technology if they think that they're going to pay the cost and take the risk while some other entity like a large pharma company is going to gain the benefit. In all of this there are many different economic dimensions and there can be many different vested interests of particular stakeholders.

There's also a set of cultural factors that are particularly relevant to biotechnology. Some technologies such as the use of embryonic stem cells challenge spiritual beliefs. But an often ignored but critical set of cultural factors is fear of impacts on the way of life. I was recently told of a European meeting of wine growers to discuss the issue of

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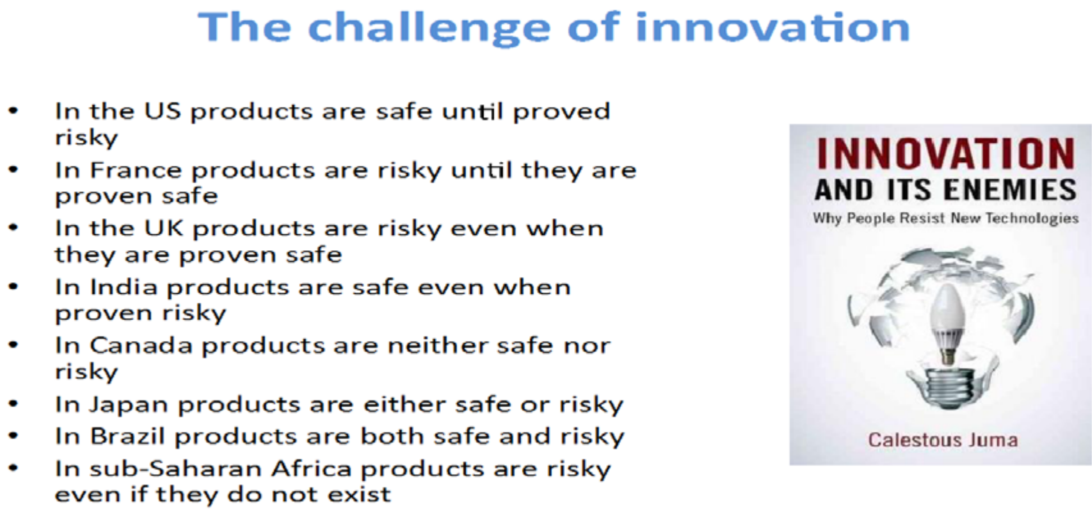
organic versus genetically modified grapes. The major objections were not economic, they weren't even about 'interfering with nature', it was simply that the technology might disrupt their way of farming that had created a valued and intimate sub-culture around wine growing: it was the fear of change to that culture which drove their objections. This issue of societal structure and culture is quite deep. Juma, in a whimsical way, describes these issues:



And while this is somewhat satirical, there is a serious point being made: different societies react in very different ways to innovation based on their societal world-views. This is exemplified by the on-going differences in the way Europe versus the United States are talking about and using gene modification and gene editing.

A societal consensus must be achieved within the frame of a diversity of values and worldviews that we value within a democracy. We need to acknowledge the inherent biases we develop from past experience and the broader range of our cognitive biases.

These considerations influence our perceptions of risk and at the heart of social licence are issues around the assessment of risk. The challenge is that risk means different things to different people. Many scientists are used to presenting risk in an actuarial sense; for example we're talking about 1 in 1000 chances of this happening or 1 in a million chances of that. But, most people don't think in those terms especially when thinking about technologies. In short, their perceptions of risk are much more subjective.

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These unconscious biases make us more likely or less likely to assess a particular situation as risky or not. And closely related are our considerations of gain and losses, benefits and burdens. You have a different sense of risk if you think you're going to benefit from a particular technology immediately, compared to if you think you're going to lose in some way, even if in either case there is some chance of harm. So, if you were a manager at a biotechnology company inventing a genetically modified plant 30 years ago, your perception of risk is likely to have been different to somebody who is not a shareholder in the company and could not see that the technology was going to produce a product that would bring any benefit to them. If you analyse many things that have been controversial, you can see these issues of gain and loss, benefit and burden, coming up time and time again in the conversation.

And in a democracy, we need to remember that politicians have a different driver of their perception of risk; it's what happens in the ballot box in 1, 2 or 3 years' time. And yet they must ultimately make regulatory decisions, so you can see that from science to society to our political representation, 'risk' has different implications.

Related to this is our understanding of precaution. The precautionary principle was never intended to say you can't do something unless it's absolutely proven to be safe. The nature of the scientific method means that one can never absolutely prove anything to be completely safe. Consider drug safety - there's always the potential that one person somewhere in the world will have a serious adverse reaction. And because of this core reality, no innovation is possible without some acceptance of uncertainty. But what has happened in some situations has been the pressure to take an extreme interpretation of the precautionary principle and reverse the concepts of science and proof; that is to say unless you can prove safety, you can't do anything at all. This is an illogical concept: but some lobbyists for a particular position can push to that extreme.

In this conversation it is useful to understand why the relationship between science and the rest of society has changed in the last 30 years. In part it is because science has changed dramatically. The result of computational development on one hand (including the emergence now of big data) and the molecular sciences on the other have changed what science is possible. An increasing amount of science, even if it is a reductionist experiment, is now framed within systems thinking which moves us from certainty to probabilistic approaches. As a result of these changes we are also moving

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from what's been called normal to post-normal science, where the science is complex and where there is a high values component that is often in dispute. This is particularly so in the environmental, social and health sciences.

The post-normal nature of the life science technologies is deeply ingrained. There have been debates over-assisted reproductive technologies, and whether they are ethical. Similarly there have been debates over folic acid supplementation of flour and the fluoridation of water. There's also on-going debate in the United States about embryonic stem cells. The genetic modification of plants and animals has been an on-going issue across most societies. I am not a futurist but I suspect that when and if new technologies engage directly with the human brain through the introduction of brain-performance-enhancing drugs or through electronic implants, the debates will be complex and diverse. The latter may involve direct links between individual people and the internet of things via implanted devices that rely on artificial intelligence and machine learning. The ethical issues that might then emerge over loss of autonomy and privacy could be very large indeed.

But, how do we constructively engage in and discuss such issues? For at least the last 10,000 years we have all by definition lived in 'experimental societies'. Humans evolved with manual, cognitive and verbal skills leading to the capacity for cultural evolution and learning that makes progressive innovation inevitable. Innovation in this context is both sociological and technological. Our societies and concomitant technological innovation have always co-evolved with iterative interactions between them. Consider the development of dairy farming about ten thousand years ago. Dairying changed the societies in which it developed, and dairy diets changed the biology of the individuals within society, allowing the mutation for lactase persistence to be selected for, and thereby strengthening those societies. The interaction continues – we continue to progress new techniques in dairy husbandry and in turn these changed technologies impact on the way our rural societies and economies operate.

1,000 years ago, the pace and diffusion of innovation was relatively slow, society adapted to it and the impact of society on the innovation was again very slow. Now we have very rapid and diffusible innovation that can have direct and large effects on society.

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But conversely modern societies have much more diffuse power structures: within populations, there are multiple empowered communities with multiple viewpoints, in turn resulting in multiple but uneven influences on technological development.

So what drives the acceptance of some technologies and the rejection of others?

First trust in the actors is really important. Of course the technology has to be useful. Secondly, the response to the pre-existing technologies and associated vested interests matters. Thirdly, it takes time. It took 100 years for margarine to be accepted. And technologies do not evolve in isolation – there is an iterative process of both societal and technological adaptation that has to occur. A progressive understanding of costs and benefits will evolve as the technology diffuses. With experience, the empirical understandings of risk become clearer. The feared effects of GM foods on health have been shown to be non-existent, and GM ingredients and foods are now widespread. This however does not automatically mean social licence in every context, for there can be many other societal objections than simply safety.

Social licence involves early and continuous engagement of the science community with society at all levels and in all areas. It understands and requires a deep understanding of underlying impacts and concerns. I believe appropriate social licence is much more likely if we engage better in the concept of co-design, co-production and extended peer-review within science. That is involving people beyond the white-coated scientists in our processes from the earliest stages. I think this ultimately means our young scientists need to be better prepared at university by training in the civic areas of science such as the philosophy of science, and science engagement. The need for social licence requires better acknowledgement of uncertainty, and a better skill set in explaining risks and benefits. We have to work out how to be more transparent and engage the community as a whole from the earliest stages, and to do so in ways that sustain and maintain trust. And society has to be open to constructive conversation.

Attitudes can change quickly – look at our society 's attitudes to gay marriage or to abortion or look what we are now seeing as relatively rapid shift in our understanding of the relationship between human existence and the environment. And here I emphasize I can only talk about Western culture – many indigenous peoples have very different and deep and spiritual relationships with their environment. Arguably this attitudinal shift first started with Rachel Carson's 'Silent Spring', with the Love Canal

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and Minamata disasters, and so on. But while these largely singular events created some momentum, it has really been the broad impact of humans on the planet that is now feeding our attention, and the IPCC must take a lot of credit for that shift in attitude: climate change, ocean acidification, widespread loss of biodiversity, contamination of the oceans by microplastics, urbanisation and the pollution that surrounds it are the very issues that many people and governments now focus on. We even have a scientific term for the impact of our species on the planet – the Anthropocene - although geologists seem to get rather excited in debating when it started!

But associated with this is the exponential growth in the planetary population which brings with it increase demand for food, energy, water and pressures and justifiable expectations for better standards of living. All of this puts more and more pressure on our environment: the demands for food, for water, for space.

These pressures are creating the grand challenges that are reflected in the 17 Sustainable Development Goals that every country has agreed through the UN system to try and achieve. And these goals highlight the complexity and the intertwined nature of the challenges we face – it is increasingly hard to sequester environmental considerations from economic and human dimensions.

We need to think imaginatively and laterally and think about how science, both current knowledge and that which is still to be done, and science-based technologies and innovation might help solve the dilemmas that flow. Tonight just let us focus on some life sciences technologies

Let us start with a 30 year old technology: genetic modification (GM). The technology was accepted very rapidly in the 1980s into human medicine; we use GM insulin, GM growth hormone and a variety of GM vaccines and yet there's not been societal concern about using GM technologies within medicine. The potential benefits of these products are obvious to most citizens. But there has been a wide range of concerns raised in some societies to using GM approaches in food, agriculture and environmental management.

So why the opposition? Many people have simply put it down to two factors; a fundamental worldview, that this is scientists 'playing god'; and/or antagonism to a major company dominating in the technology, as originally occurred in the seed sector.

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But there have been other deeper factors in play. There were economic factors affecting companies on either side of the Atlantic: the Americans were heavily into the technology while the Europeans, with their big chemical companies had fallen behind. With this there was pressure put on the European governments to protect their interests. There were European concerns (e.g. the wine growers) over the sociological impact of commercial scale farming. There were valid fears of the unknown. But these were often exaggerated for marketing or political advantage. There has been claim and counter-claim from both sides of the debate. There has been much confused information, hype and exaggerated claims of both risk and benefit, and heavily laden language used (eg 'Frankenstein foods') that has arguably inhibited constructive societal discussion.

And in response there was sadly a strong Mertonian attitude from many in the science community not engaging in the conversation, but often also not being able to because of the narrow and polemical nature of the public conversation. But we now face new and important conversations about more advanced techniques – essentially natural mimicry achieved through what is called gene editing. Does gene editing (GE) have a role beyond human medicine? Is GE distinct from genetic modification? How could it be used? Can we separate the reality from the hype? Are there biological, ecological or health risks of significance or not? The issues will get larger as biotechnology moves beyond GE – for example to apply meiotic gene drive techniques perhaps to eradicate mosquito-borne diseases, to eradicate other pests or to use synthetic biology to mitigate greenhouse gas emissions resulting from agriculture (for example by altering the bacteria in the rumen). Biotechnologists need to engage better and earlier with society.

So now let me focus on these and related questions in relation to our environmental challenges. These challenges arise from the reality that we now have 4 ½ million people living in New Zealand and largely living off the back of an agricultural and increasingly touristic economy. In the interests of time I will use but two examples to explore some choices ahead of us regarding biotechnologies and the environment:

- Predator free NZ 2050 and protecting our biodiversity
- The future of pastoral farming, water quality, land-use and meeting our climate commitments

Both arise from the consequences of humans invading this land. While it started with

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the arrival of the Maori, dog and kiore, the transformation accelerated with the arrival of Pakeha. Over the past 200 years land was cleared, waterways were dammed for agricultural, industrial and domestic use and our agricultural land was turned into giant exotic monocultures of ryegrass and clover. Multiple exotic species of plant, bird, mammal, fish and insect were intentionally or accidentally imported and the consequences to our indigenous flora and fauna are well understood. Certainly we preserved important areas in national parks and conservation land and collectively were proud to do so. But outside these areas there was not been much consideration about what happens to our land and waters. We thought that we could exploit those openly without consideration of the deeper issues because we had put conservation land aside.

And of course primary production has led to a very major environmental footprint and this has been our collective blind-spot. As farming was integral to both our economy and our sense of nationhood, we have tended not to notice the environmental consequences; particularly of a laissez-faire view of enabling land utilisation with a minimum of regulatory constraint. The consequence has been that given the high returns for dairy farming we have seen both productive and more marginal land shifted to dairy at the expense of other products, and that has led to more rapid environmental degradation, deforestation, erosion, increased methane production and freshwater contamination by phosphate, nitrogen and faecal material. But the simple reality is that we rely on agriculture and we have relied on the underpinning life sciences that for 60 years have sustained our agricultural economy to keep us wealthy and to give New Zealanders the quality of life they want.

And on top of that we now have the challenge of anthropogenic climate change. We have made commitments to address our greenhouse gas emissions, we have a growing concern over the balance of land use reflected particularly in discussions around freshwater, there are many challenges in the management of our marine estate which we poorly understand, and we have ongoing threats to our remaining biodiversity as a result of exotic predators such as stoats, possums and rats, not to mention feral cats. We have problems of imported wasps destroying our native bees, we have to confront biosecurity incursions repeatedly, we have myrtle rust, kauri die back and *Bonamia* to name but a few.

New Zealand faces the reality of being geographically isolated. That means that our

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position in global value chains is challenging. For countries such as ours, primary production and its derivatives are likely to remain mainstays of our economy well into the future. Diversification away from an economy focused on the primary sector will be slow, and in many ways limited by the realities of global value chains and by the challenge of the retention of growing companies in NZ – a problem all small advanced economies face and which is not unique to us. While the technology sector is growing outside the food and agriculture sector and will bring a growing return, in the foreseeable future agriculture and tourism will remain at the heart of our externally facing economy. The arising challenge we have long recognised will be how to get added value before that product leaves our shores, and that must include on-farm as well as off-farm considerations. We now need to use science to help take us forward and solve these dilemmas.

Let's start by considering the challenge of Predator Free 2050 to illustrate the opportunity and the challenge. This is far more complex than simply fencing and trapping – we must recognise the reality that all these predators are also present in our urban domains. One of the intermediate goals set for Predator Free 2050 is to have a strategy to eradicate one species of predator by 2025 – that is to have the strategy and technology clear, not to have actually eradicated the pest by then.

The first issue is which species – rats, stoats or possums. And can we eradicate one species without opening the ecological niche for another pest to occupy? There are arguments in favour and against each of these species being the first target. And why focus only on mammalian species? Because they are very obvious, but what about the exotic wasps that posing a threat to native birds and insects in honeydew beech forests? Here you see the interface between scientific considerations and public sense of priorities – they are not always the same.

Trapping, fencing and sanctuaries do not achieve the vision although they may protect vulnerable species. We already use poisons – think of 1080 – but there is a broader range of possibilities – what about chemicals that induce sterility? What about using biological warfare such as bacteria that infect and cause sterility in the target species? What about using bacteria or plants to produce inhibitory RNAs that are very precisely targeted? What about meiotic gene drive, etc? All of these are conceptually possible but each one of them cannot be developed and applied without social license, which can never be taken for granted. National conversations of a very

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different and mature nature will be needed to use any of these approaches.

So let’s take that conversation a little further and consider the future of pastoral farming – and lets not kid ourselves, we still need it. Imagine our economy if we were faced with a pandemic that wiped out our dairy, beef and sheep industry overnight – it is the kind of mind game we have to play to understand the issues.

The raft of new plant breeding technologies that are emerging offers enormous potential. Some countries have ruled that those that do not introduce foreign DNA are not genetic modifications, provided that they reflect edits that could occur naturally. Others are less certain, but the extent to which these are deep philosophical objections or reflect non-tariff trade-barrier positioning or other political considerations is not clear. But the technology is developing fast and newer and more pervasive methods will be developed.

For example, could we increase the rate of tree growth, reduce risk of wilding conifers and change the economics of natural carbon capture and thus marginal land-use? Could we produce different forages that change the productivity and the value of our pastoral farming while reducing nitrogen release, greenhouse gas emissions etc? Could we enhance our cropping industry and see land shift back from animals to much lower environmental footprint cropping – say for the production of artificial meat and milk? Some calculations suggest we could reduce our pastoral GHG emissions by about 15-20% by such approaches – in particular because we could sustain productivity while reducing stocking rates dramatically. But we really do not know without testing them in the real world.

We face a challenge of decline in phosphate supplies, and most phosphate applied to the land is not taken up by plants but ultimately ends up in our waterways with consequences of eutrophication. Experimental plants have been developed which have 4 to 5 times the uptake capacity and thus reduce the need for phosphate fertiliser by about 75%. This would have multiple benefits.

We have heavy metal and pesticide contamination is some sites. Bioremediation refers to the concept of using live organisms to either degrade the pesticide or harvest the contaminant for removal. Synthetic biology can develop bacteria that will degrade all sorts of contaminants and modified plants can be developed to harvest metals and pesticides.

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All these are possibilities and the world is changing fast. The logic of regulation by process rather than by trait is increasingly questioned around the world especially with these newer techniques that mimic nature as opposed to traditional genetic technology. But even traditional genetic modification cannot be ignored. South Africa would have faced a major food crisis last year as a result of serial droughts associated with major terrestrial warming had it not been for the availability of non-commercially sourced, drought-resistant GM maize. We are seeing a raft of new gene edited strategies emerge with other desirable outcomes – for example sheep have been reportedly developed in China which do not need their tails docked because they are naturally shorter.

We have societal choices ahead of us that are hard – where environment, economics, agriculture, and industry interests all intersect. These are decisions that science alone must not make. And the decisions we make today may differ from those we will make tomorrow when newer technologies emerge. We will use some technologies and likely choose not to use others, but what is certain is that the technological weaponry we will be using in a decades' time will differ from what we now use. The challenge is how to have the conversations and what should be the regulatory regimes that allow for rapid technological change.

This is where enhancing the public understanding of the scientific processes themselves are critical. The participatory science programme, funded though the *Nations of Curious Minds* initiative is an attempt to do just that. But citizen science in whatever form is not enough. We need to take lessons from the language and scholarship of post-normal science: the answer must lie in concepts like extended peer review, co-design and co-production. These are critical but complex and controversial concepts but they will be a large part of the future of science. It will require major changes in how science is managed and funded, how our research institutions act and how researchers are incentivised. The scientific enterprise is inherently conservative and this will not be an easy road for many.

And I cannot finish without pointing out that the benefits of environmental and biological research have many other spill-over benefits. Beyond the clear benefits of an improved environment, there are benefits of a more diversified economy, the potential for enormous value added in our food sector and real possibilities in clean-

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tech, environmental technology and agritech. Ultimately science and many new technologies will be essential to enhancing our environment, but that science will mean nothing without much better national conversation, getting beyond political or interest group point scoring and ensuring that conversations engage the public, NGOs, the private sector, academia and the policy community. Science can make a difference.

Thank you.

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