Science Council 2009 Roberts Lecture
Priorities for Science in the 21st Century - Professor Sir David King
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It's a very great honour to be standing before you to deliver the Sir Gareth Roberts Lecture and in particular it is very real pleasure to be able to honour Gareth in this way. Thank you for giving me that opportunity.

The power of knowledge

I'm going to start by saying that I think the power of knowledge as we have developed it through the twentieth century, starting back in the eighteenth century, is not really recognised in the political world. In the private sector, the understanding of what you can deliver in competitiveness through current science and technology is clearly understood and you understand that you get wiped out by your competitors if you don't. But in the public sector, and in governments around the world, I would say there is no real understanding of what could be delivered, let's say for the betterment of mankind, and for the betterment of populations and governance, though the application of science and technology.

Let me give you an example. The awful situation with the tsunami off the Indonesian coast in December 2004. In that tsunami the number of people who died is estimated to be about 230,000. A cataclysmic event and it was predictable. I had to report it to the Prime Minister, on the 2nd/3rd January 2005 that seismologists (people who study volcanic activity and who understand plate tectonic movement), had produced a map of the world which demonstrated that the next big cataclysmic event that would occur along the Sumatran Trench. They predicted that a force nine tsunami would evolve from that particular event. They couldn't say it would happen on 26th December 2004, but what the scientists did say was that because of the pressure building up on this collision between the two great continental plates, that an event of this kind was becoming more and more inevitable. There were two groups of seismologists, one from Oxford and one from California, who visited Indonesia, Sri Lanka and India to say: *"You need an early warning system in the Indian Ocean because this thing is going to go".* None of those governments responded positively at all. In fact the scientists couldn't find a route in to speak to the governments.

The point I'm making here is that with an early warning system in place, the number of fatalities might have been reduced to 40-50,000. So the lack of an early warning system and all that it encompasses - if you have a fire alarm system you also have to practice with exercises - the absence of that meant a massive additional loss of life. And this is not the first time. Now we are putting an early warning system into the Indian Ocean. Classically we wait for the disaster and then we put the early warning system in place. The same group of seismologists had previously predicted a tsunami off the Peruvian coast. They got that one right as well. Massive loss of life. In goes the early warning system. Actually closing the door after the horse has bolted – although the risk with the Sumatran Trench remains and another disaster is predicted, so it is a good thing we are putting that early warning system in place. But my message here is simply: why was there no channel of information between the scientists who understood the nature of the problem and the governments who were making decisions to safeguard their people?

I'm not suggesting that those countries that I've just mentioned are actually worse at this than any others. It's only since I've started making a fuss that the City of Los Angeles has put a plan in place: because it is Los Angeles, I'm afraid, where the seismologists are saying the next big one is going to happen. There has never before been an exercise for the potential massive plates' collision leading to a disaster in that area.

Population growth

So how do we move on from this situation? I'm going to come back to that point. I want to talk about the successes of science and technology and express this in a very simple form. I want to say that actually science and technology - agricultural advances, engineering, all that that encompasses and medical sciences - has delivered a massive amount for humanity in the twentieth century. We entered that century with a life expectancy of forty, forty-five, and we left the century with a life expectancy of eighty, rising still. An exam question. Life expectancy is rising linearly with time. Why? Why isn't there an asymptote appearing in time?

But there's a down side. I'm not going to gain say the achievements made in the socio-political sphere as they were a big part of what delivered those advances. The downside is that as people live to maturity they tend to form, if I may use a scientific expression - breeding couples - and breeding couples breed and so population grows. For every society - let's not look just at developing countries, for our society - as wellbeing improves, as the civil engineers move in and provide clean water and hygienic conditions, population explodes. It happened in Britain, it's happened in every country in the world. We have female fecundity that starts at around seven or eight average number of children per woman, of whom only two survived into maturity on average, giving us a stable population, give or take a Black Death. (Sorry that wasn't meant to be humorous.) Then what happens is wellbeing improves (blame the civil engineers) and we suddenly have all seven or eight children surviving into maturity. Up goes the population because those surviving into maturity also have children. It takes women two generations to understand what's happening and then female fecundity collapses down to that magical number of two. Britain now has a rate of 1.85 and we are hitting a stable population. Globally the population will also stabilise.

Having arrived in the beginning of the 20th Century with a total of one and a half billion, we started adding a billion every twelve years in the century. We end the century with six billion. I'm going to suggest, it's this large number that is the big challenge we're facing in the 21st century. That number has qualitatively transformed the nature of our challenge as a civilisation as we move forward.

Life Expectancy

I want to draw your attention to the life expectancy variation around the world. (Slide 1 – Variation in Life Expectancy Around the World). Life expectancy is improving everywhere except Africa and sub-Saharan Africa, and in some places it is actually going backwards. What we have for most of the world is a wonderful story in the 20th Century: look at India. They have rapidly rising population but nevertheless the life expectancy is over sixty for a very large, dense population.

But then look at Africa the one continent in the world that has not benefitted from these transformations: it is the continent that has actually suffered from our aid programmes. I don't suggest that we have taken our eye away from Africa, but rather the manner in which we have dealt with Africa has been misconceived in the extreme. What Africa needs is much more science, engineering, technology, and agriculture: skills are what Africa needs. What it doesn't need are the people who want to see Africa go back to the Middle Ages. And I'm afraid the international development community has unbelievably taken the second of those two alternatives as its programme of work. I think it's now changing as we now understanding that societies only develop through what we might call an 'elitist operation' working through higher education as a key to developing skills, and developing all the way down the skills agenda right through to every member of the workforce. This change is not being delivered through 'well meaning' operations in Africa. The programme of work that is going to deliver advances for Africa is going to be related to human capital development. It's related to the skills development of the people in that continent. Worse, they are losing a net 100,000 skilled people a year to the extent that the attempt they are making through their own schools and universities is being depleted through the attraction of jobs in the rest of the world – though of course it is quite understandable that people in Africa are leaving if they are sufficiently well qualified to get jobs, for example, as nurses in our National Health Service. I'm going to move on from the problems of Africa but I would love to discuss it with you during the Q and A.

As we move through this century entering at 6 billion population we are now at 6.7 billion. (Slide 2: Total Population of the World in Billions) We will pass 8 billion in 2028 and you will see that if we take the median projected figure, you'll see that there is a plateau or even a maximum at mid century of 9 billion people. What is happening is that female education, female empowerment, together with the availability of contraceptives, are keys to the self-limiting process of population growth. So in terms of offering best value for money for managing population growth, those are the those three key factors. I'm not saying that blokes aren't involved, I do understand the process, but they're just less reliable!

What this means is that we have to plan today for 9 billion people in 40 years time. That's the nature of the challenge that faces us. Not just managing 6.7 billion people on this planet, but managing 9 billion people, all of whom aspire to a standard of living that I see in front of me here.

Resources management - a paradigm shift

We are also seeing economic growth in all of those countries, apart from Africa. That means there is a greater demand on resources. I now want to focus on the question of resources management as we move forward in time. Do we have the resource capacity? To encapsulate what I am going to say: I think this demands a true paradigm shift in our culture. A paradigm shift in which we become like the indigenous people of America and Australia, who respected their environment and managed it as they lived, and who wanted to leave the environment for their sons and daughters in a way that they had found it. That was a big part of their philosophy and we have lost track of it. We have not put a value on the management of our environment, on the management of our land and on the management of our oceans with our economic system. We need now to enable shift in our cultures so that we embed in all of our thinking the management of our environment, the management of the bio-diverse system that yields the ability for human life to continue on the planet: it is as fundamental as that. I'm suggesting that this paradigm shift hasn't yet entered the mainstream of our political, cultural and private sector thinking. We need to manage the problem of using up resources faster than they are being replenished naturally, AND we need to address the mismanaging of those resources. If we don't, we will leave our successive generations with a massive set of problems, problems that are closer than most of us appreciate.

Scientists need to rethink priorities

So, let me then say with the hope that I won't be misunderstood. We have developed through science and technology and I'm and now pointing at scientists and saying: you too have to rethink your priorities. We have developed ourselves in a way that we are better able to understand how to land a spacecraft on Mars, better able to understand the properties of the Higgs-Boson, than we are able to understand the cause of millions of deaths in Africa from HIV AIDS or manage it; we have not addressed malaria, poor nutrition or developed renewable energy sources that are suitable for our sustainable development. All of these challenges have passed us by in our great rush to manage problems that we were taught were the big problems when we were young scientists at university. I'm suggesting now there's a new set of problems that we need to bring to the fore in our thinking.

21st Century Challenges

What are the big challenges I'm talking about? I'm pleased to say this slide (Slide 3: 21st Century Challenges) is coming to be known as the "King Carousel". If you look at any one of these challenges - whether it's food, water, disease, climate change, energy, the ecosystem services that we require, land, conflict and terrorism - you see that we cannot tackle them in isolation from each other. This is a highly interactive system. So we have I'm afraid, in physics terms, a many body problem.

Let me look at water resource. The water resource problems are with us now. If we take fresh water resource as the population expands, we use more water, we contaminate more water and the population continues to expand so our demand on water is increasing. (Slide 4: Water Scarcity) This means that we've got a curve of available freshwater going down and the demand going up, where do those curves cross over – by mid century. At the current rate of increase of consumption, mid-century, globally we will have a

problem. But globally never mind. What about locally today? I give you as an example not Darfur or some dramatic example like that, but the state of Victoria in Australia. The state of Victoria in Australia used to be the great agricultural province of Australia but it has had eight, perhaps nine successive years of drought. The farmers have left the land and the state of Victoria is having to desalinate seawater to produce freshwater for cities such as Melbourne and all the cities and towns of the state of Victoria. They have two problems: one is that they have used the freshwater from the freshwater aquifers faster than they were being replenished by rainfall; and secondly, rainfall itself has been diminished by climate change which is producing desertification from the southern tip of Australia through South Australia and Victoria up northwards. So that green patch on the edge of Australia is becoming dry and desertified. By the end of this year, one third of the freshwater supply of the state of Victoria will be from desalination. One third of their freshwater supply requires a massive programme of building desalination plants. And you could say: *"Well Dave King ought to be very happy with that, technology has provided a solution".* But of course there is a problem. The solution comes back to energy supply because desalination is an energy intense process. The problem is a triple one because Australia has a lot of coal and, believe it or not they're firing up all the desalination plants with coal. So we come back to climate change which is caused by burning fossil fuels and deforestation, of course. So the very problem that is contributing massively to the creation of desertification in the state of Victoria, is being exacerbated by the solution. What this shows us is that we have a great deal of thinking to do to see how we solve each one of these problems.

Loess Plateau example

Now taking the example of ecosystem services. Some of you may know that in China, the Hang Dynasty began on the Loess plateau. Around the Loess plateau flows the river that they used to call the Mother River, the mother of the Hang people. The Hang people became the majority people of China, controlling the civilisation and they completely over-farmed the area. It became totally eroded and desertified with the result that in 1420 the Emperor moved the Hang people to Beijing because it was a green area and they started the farming there. That is an example of ecosystem services collapsing because of overuse by mankind. By the way, the Chinese government, in a massive and impressive exercise, has got the biggest reforestation programme in the world. So far in the Loess plateau, an area the size of France, they have already reforested and re-agriculturally planted an area the size of Belgium. President Hu Jintao recently announced that by 2020 they will have reforested the whole area. This is a massive programme of work. There is nothing like it happening anywhere else in the world. This will become a regenerated area which will be a massive new agricultural centre for China. It's a high rainfall area. And I didn't say, but the Mother River, which after the desertification of the Loess Plateau became yellow because the yellow sands were swept into it by the rainfall, became known as the Yellow River. So this illustrates that we need to understand that if we try to manage food production by over-intensive farming, we wreck the ecosystem services that we all need to survive with. Managing this circle is a very big problem.

Food supply

I'm going to develop the argument around food. It's a commonplace to say that we need a third green revolution to feed 9 billion people without causing further disruption due to mankind's massive footprint. Why third green revolution? We've had massive green revolutions in Asia. In that part of the world we have seen the improvement of food crop productivity by an average sevenfold. For example, the India of the 1960's never expected to be able to feed its own population but has managed that trick by a massive improvement in crop productivity. How did they do that? They turned to science and technology. To improve the quality of the crops and to manage the crops that were suited to the actual terrain that the actual crops were being planted in. We need a further sevenfold improvement to address this problem. Put another way, we need roughly 50% more crop production not by 2050, but by 2030, to meet the current growing demand. I stress, 50% more crop production.

Can we do that and manage our ecosystems and manage the footprint of mankind on the land mass that is available to us, faced as we are with desertification brought on by climate change in some areas and flooding in others? I believe the answer is yes, but only if we can be smart about it and make use of what

modern biotechnology can deliver for us. I believe we can do this. But the problem here is related to the social acceptability of what science and technology can offer for us.

Let me just point out what happened in 2008 to food prices (although I suspect in this audience we barely noticed the impact). You'll see that the rice prices went up from $300 per tonne to $800 or $900 per tonne over a relatively short period of time. When you have one billion people on the planet living on less than a dollar a day and basic food prices go up like that, the number that are malnourished or dying of starvation goes rocketing upwards. And that is what happened. Our analysis at the Smith School in Oxford indicates the two factors that contributed to this. They were first of all, the US policy on - I would describe it as a farm subsidy policy - on converting food products into substitutes for petroleum products. So turning grain into alcohol and putting the alcohol into petrol, which was a policy to try and cut down the dependence on foreign imports of oil (I don't believe it was related at all to managing climate change). This was roughly 70% of the cause of that food price hike because it meant that the United States surplus food that would normally go into the general food supply around the world, was no longer being used for that purpose. Secondly, there was a big flood in the Asian area early in the planting season, which had a big outcome in terms of the destruction of the crop. The reason I'm making this point is that every year there is a loss of rice due to flooding. Every year it's quite a high percentage, 5% or 10% of the potential rice product is lost in this way. This year it was considerably higher because of an early monsoon.

Genetic Modification

You need, of course, to plant rice in a paddy field where there is going to be a lot of water. You've got to time the planting right because the young rice plant can only last about three days in totally flooded conditions and it has to be drained while it's a young plant. Except for what was discovered in India. In 1992 a wild form of rice was identified known as FR13A FR for flood resistant. This wild rice could survive for three weeks in total flooding conditions and still sprout up and survive. So what do you do then? Use modern biotechnology, genetic markers, find out exactly which genes in the wild rice are giving it this flood resistance? But the wild rice is not commercial. So snip those genes, put them into commercial rice plants and problem solved. I'm going to just illustrate this with this slide: the normal commercial rice on the left grown under the same flood conditions as the genetically modified rice on the right. Flood resistance can be managed using modern techniques. It was discovered in 1992 and we are hoping that next year it will be planted around the world. Why has it taken so long? Simply because the farmers won't plant genetically modified plants, because they think the western market has rejected them. The net result is that these products are being produced by standard plant breeding techniques but using genetic markers to speed up the process. So it's taken a decade and a half to do this by standard plant breeding techniques whereas it took three weeks to do it in the lab. And how many hundreds of thousands of people have died as a result of that delay? I'm simply suggesting that this lifestyle choice of ours, to reject GM products, is a lifestyle choice only for those of us who can afford to make such a choice. For people in the developing world this isn't a choice that they can afford to make. It's a matter, literally, of life or death. I challenge those that have taken such a negative view towards all GMs - including snipping genes from a rice plant into another rice plant - that they need to think about the damage their position has taken globally.

This is just the classic reminder, that if we do go back to the original maize plant, it doesn't exactly look anything like the current commercial maize plant. This process of genetic modification has been with us for a very long time and staple food stuffs are produced by genetic modification. Let's not rule out the tools of modern science because of some prejudices. Rather let us make sure that we have governments introducing proper regulatory systems. As the science advances and produces more new products we need to make sure the regulatory system keeps up with it. Don't rule out what science can deliver for mankind rather see that governments keep up with it. The downside if we don't do this is that people are planting GM crops, but they are doing it, if you like, illegally. That means it's completely outside a regulatory system. This is exactly what we don't want to see happening.

Climate change – global warming

The biggest problem of all is global warming. When I started talking about global warming in 2000, the various international bodies, including the World Wildlife Fund, the United Nations, the World Bank, had put out reports on the big challenges facing us this century. Those reports did not include climate change in the top ten. Since that time we have seen a big transformation in the realisation that this is a massive challenge and that it is a challenge that is with us now.

When I first spoke about it back in 2000, I didn't have many friends. Yet we had data from palaeoclimatology, beautiful data going back 200,000 – 300,000 years. This was obtained from ice cores taken both in Greenland and in the Antarctic. Ice cores were also taken from mountain tops. (Slide 5: The Rise in Emissions to 2100) But now we had data, as I'm showing you up here, going back more than 60m years. At this point the ocean sedimentologists got in on the act and saying: *"We can take cores from ocean sediments and we can go back much further in time than you ice scientists".* The nice thing is, as always in science, these two totally different techniques are producing a complete overlap for 850,000 thousand years. So the furthest back in time for an ice core is 850,000 years (that's a three kilometre long ice core). The ocean sediment data though goes back much, much further. For one reason ice didn't exist on land in this period 50m years ago.

What I have up here is ocean sediment data going back 60m years. The present day is zero on the right hand side, 60m years ago here, and what you see is the temperature, using oxygen 18 as the proxy for temperature, on the vertical scale. In the period about 45-50 million years ago we went through a global temperature maximum, that is the Miocene-Pliocene transition, and in that time the temperature is about 12^{o}C above our pre-industrial level. It was quite hot on the planet and certainly mammals were not comfortable between the tropics. The Antarctic was a sub tropical forest, and if you drill through those ice cores, there you find the remnants of the forest and the large mammals that existed in Antarctica at that time. At that point in time, the only real estate to have had property in would have been Antarctica.

It took about 50m years for the greenhouse gases that were in the atmosphere at that time to fall and bring the temperature down with them. We have greenhouse gas levels 1,000, 1,500 parts per million at the maximum and they fall down to levels between 200 and 270 parts per million. We have a remarkable stability in the amount of greenhouse gases over quite a few million years. You see from that red line 3m years ago onwards, carbon dioxide levels in the atmosphere are very stable and the temperature is very stable. Well it's very stable up to a point. The noise isn't noise at all, those ups and downs there are of course the planet coming into a biphasic system - the temperature becomes biphasic - it's either cold or warm or in between the two. Well done to the scientists in the chaos area. We hit this bi-stability in the system and of course the cold temperatures are the ice ages and the warm periods are the interglacial periods. We come to the present warm period and I expand on the scale here. So we are 400,000 years ago. We're in an ice age, warm period, warm period, so the warm periods are very short. We have carbon dioxide levels up here, so we now have ice core data, so we've got the carbon dioxide levels and there's a pretty good correlation. The beginning of course of the transition is due to a change in the planetary orbit. But the change in the planetary orbit kicks off carbon dioxide levels here, which then emphasises the rise in temperature. We have a feedback system causing this effect. Then we come, out of the last ice age 18,000 years ago, to a little blip and then we're into the current warm period. Fortunately for us this is the longest warm period on record, and so we've had 12,000 years of constant temperature: a very unusual period. By the way, not just constant temperature but constant sea levels, because as we go from an ice age to a warm period the ice on land melts and goes into the sea and up goes the sea level and it rises a 100-120 metres. So the map of the world changes as we go through this. Russia was connected to America during an ice age and you could say it might have been good for the world if it had still been connected in the warm period. So why is this warm period so long? That in itself is an interesting question. Look at the carbon dioxide levels. Classic ice age level, two-hundred. Classic warm period, two-hundred and sixty. And it's been creeping up. This might be the first impact of humanity on the climate system, if this can be attributed to the removal of forests to create our agricultural system.

We see a creeping up of carbon dioxide levels, a lengthening of the warm period and then something happens up in Manchester. We discover the steam engine. We start using fossil fuels like there was no tomorrow and up goes the carbon dioxide level and we're now at three-hundred and eighty nine parts per million and going up at two parts per million per annum. That's the challenge were faced with on climate change. It's the consequences of this unprecedented rapid change in carbon dioxide levels. As we have taken naturally sequestered carbon as oil, gas and coal and burnt it to create all of that wellbeing that I started the lecture with. This improvement in our life expectancy has been delivered by providing energy through fossil fuels. The question is in palaeo-climate terms, how far back have we gone? We've gone roughly back to where this red line is and have we've taken the planet out of the next ice age: that's the good news. Even as the planet wobbles now it will not take us back to another ice age. We've got out of those ice age warm period oscillations. The bad news is that we're about 30 years behind catching up with the amount of carbon dioxide we've put into the atmosphere, because we put it up so quickly, there's about 30 years of inertia in the heat capacity of the oceans.

Adapting to the impact of climate change

Adapting to the impacts of climate change is an essential necessity as we move forward in time, even if we were to stop carbon dioxide levels where they are now. That's a very important part of the message. And of course the other part of the message is: *"And how far back could we go if we really burnt all of the fossil fuels at our disposal?"* I believe if we try hard we really can get back to that point there. As a scientist who works both in theory and experiment I love to test theories with experiment, but this is one time I think we give this a miss.

Where do we need to go? What is the lesson from all of that? My colleagues in my new school in Oxford managed to get a few papers in Nature and even got on to the cover of Nature so we're quite proud of it. The idea was very simple. It was how much carbon have we already put up into the atmosphere and into the oceans since the beginning of the industrial revolution? And the answer is about half a trillion tonnes of carbon have been burnt through that process, through our industrialisation around the planet. Then the question becomes, and how much more can we burn before we are guaranteed to go beyond two degrees centigrade temperature rise, which has become the number that people are saying we should stay below. I'm slightly sceptical about the choice of that number, but nevertheless, the answer is another half trillion and we are cooked. So if we put another half trillion tonnes of carbon up there we certainly start exceeding the two degrees and start heading quite rapidly towards three, four, five degrees centigrade temperature rise. There's the big challenge, because, at the moment our use of fossil fuels is still growing year on year.

I should pause just for a moment and I think this is quite an important pause. I have to modify that statement, it was exponential growth. In 2008 the global emissions of carbon dioxide fell by just over four percent. I don't of course know what the figure for 2009 will be, but let me predict that the fall will be compared, not with the previous year but compared with 2007, will be more like 9%. So a 4% fall followed by at least a 5% fall. That is course due to the economic crisis and the old business-as-usual scenarios have to be recalculated. If we now do a recalculation to 2020 our best figures are that by 2020 carbon dioxide emissions will be between 15% and 25% percent below the business-as-usual scenarios. Through this economic crisis - there's always a silver lining, we bought ourselves a bit of time. And really that is a distinct advantage because the state of the negotiations on mitigating carbon dioxide emissions are not going to yield the results as quickly as we need to see them. I think it's a very important factor that we have actually managed, through no deliberate attempt on our part, to buy a bit of extra time in terms of global warming.

This is the curve that illustrates the old (I'm afraid, this curve hasn't been corrected) business-as-usual scenario. That's billions of carbon dioxide emitted per annum rising with time here. We see that if we want to avoid a two degrees rise, we need to be on this stabilisation scenario. This is a simple diagram which illustrates that it's not just a developed country problem. Even if all the developed countries went to

zero, we still have a problem rising up here so we need a solution which encompasses all countries. As we look at the needs for a global agreement, my first point is that we have to agree where we are going. And I'm afraid that Copenhagen is not going to deliver that this December. This is my *"de minimis"* requirement towards actually managing the problem. What is the level of carbon dioxide in the atmosphere that we agree we should stay below? If we all agree 450 parts per million – then OK because that will then take us to the next step. What are the national dynamic targets, time dependent targets, as we go forward in time? For the developed world, that means we need a downward target, year on year, from now on. For China we might say an upward and then a downward trend, and for India a longer upward and so on. But we need agreed national targets for each and every nation or group of nations.

Carbon dioxide trading

How do we do that? This is critically important and carbon dioxide trading is my preferred way forward. I believe the alternative of a tax, a carbon tax, is very similar in economic terms but has a massive disadvantage because taxes are imposed by individual governments. Carbon dioxide cap and trade is a trading process, and trading prices are then not in the hands of governments which change and provide incentives in democratic processes for an opposition that comes in saying, we will lower all those taxes including the carbon tax. Carbon dioxide cap and trade, putting a price on emitting carbon dioxide, is, I believe, the essential part of the process. We need to make sure that the market system works by putting a price on the behaviour that we want to turn off.

And that price, what should it be? In Europe at the moment it's only 13 Euros per tonne: the price needs to be at least 50 Euros per tonne, perhaps a 100 Euros per tonne, so that we switch from this fossil fuel dependency to a low fossil fuel economy. How do we create a large price? We create a large price by depressing allowances year on year, so that we have targets that are agreed and set that are both realistic and will manage the problem. We need also to recognise the needs of developing countries.

My view is quite simple, and I note that President Kagami of Rwanda has taken up this position on behalf of the African Union. It is that all nations should be given targets, including Rwanda, which is currently at 0.35 tonnes per person per annum. Rwanda should be told "your target is the same as ours". So in Britain we're saying we will reduce our emissions by 80% by mid century. We are currently emitting 10 tonnes per person per annum. By mid century we will be at 2 tonnes per person per annum. Rwanda should be told it can have 2 tonnes per person per annum as well and you can trade at your current level. That gives Rwanda the incentive to develop its economy along a low carbon trajectory from the beginning. The alternative, and this was the inherent threat in Paul Kagami's speech to the United Nations, the alternative is that we are encouraging Africa to be the smoke-stack manufacturing industry of the future. They will find that companies out-priced in terms of carbon dioxide emissions in developed countries will move their factories to Africa. Then we will buy back the goods that they make with the embedded carbon in them and the problem is not solved. Kagami is asking, do you really want Africa to develop as a high carbon economy before it goes on that downward trajectory? If not, then you'd better include us in the problem and allow us to be part of the solution. It seems to me that is the only sensible way forward at this point in time but it's not even on the table for Copenhagen at the moment.

Global energy demand

Let me just switch to the most complicated diagram that I have: it's Julian Allwood of Cambridge that you can blame for this. (Slide 6: Global Energy Demand) Actually I think it is a brilliant piece of work and those of you who are engineers will immediately recognise the engineers behind this. There are many discussions about how we lower carbon emissions and many of these discussions mix categories and the mixing of categories means that you get double counting in how you are doing your carbon saving. What this figure says is there's a category called energy sources on the left hand side and there's a category called final services on the right hand side. You cannot mix these when you are adding carbon saving. Right so we need to look at our energy sources which is where we urgently need to de-fossilize. We need to see that, for example, the UK must have a nuclear contribution (an increasing contribution in my view) rising to

roughly 30-40% of maximum peak demand of electricity. This means that at minimum demand, most of your electricity is coming from nuclear. Because nuclear produces electricity all the year round, that way you minimise carbon dioxide emissions and you minimise electricity cost. The French position on 80% nuclear into the electricity grid is an expensive indulgence I think.

So as we move forward in time we need to be making sure we optimise these non-fossil fuel contributors. Biomass by the way, looks on this to be quite healthy and many people like to add the biomass bit to the renewable bit and say that's already a significant proportion. The biomass bit is largely unhealthy, with much of it is occurring in Africa where it is simply removal of forest. There is no replanting as the burning of the biomass occurs. We look at each aspect of this - efficiency of conversion devices, the passive systems - it's a massive area for the scientific community to investigate. There are the high carbon parts of industry: manufacturing, steel, chemical, minerals, paper, food, aluminium - these are high carbon in the way they are currently operated. For example, take steel: where we take down an old building what do we do with the steel that was used in that old building? We send it to the furnaces. Aren't there cold working, compressional processes that can be used instead of the high temperature? The solution at the moment is always "we can burn it". Let's look for low temperature solutions to all of these problems.

So we need as scientists to be examining each one of these categories and each element in it to optimise the processes. Energy efficiency gains are the big win-win of the whole process. If we're looking at economic costs, there are two factors: one, first take the low hanging fruit, go for energy efficiency gains. Every company that has taken this seriously has found massive savings from that process: we have just been profligate with our use of energy. But secondly, we need to be examining nearby alternatives. Quite honestly, every time we think about this we realise, we have never been challenged by energy supplies before and now that we are, we find there is a plethora of solutions available to us. As soon as we are challenged we find alternative solutions: that's what science, engineering and technology is all about,.

I give you an example. When we discovered that CFCs were responsible for the loss of ozone in the stratosphere a partial ban came into place. The chemical industry immediately screamed saying: *"No we can't do that!"* and *"The jury's still not in on CFCs and ozone."* Then the same chemical industry began to produce alternatives to CFCs because there was a little bit more money in the alternatives. Then they all came back and said: *"No, we can manage this problem and we can manage it much more quickly."* We know how to find alternatives, we just need the incentives to find the alternatives.

Solar energy

There is a note of optimism that I feel I need to put into my talk. Here's the question: How much solar energy reaching the planet's surface would we need to use if we could efficiently convert it into usable energy in the form of electricity or heat for all of our requirements? And the answer is the amount of solar energy landing on the six small squares indicated here (Middle East and North Africa (Saharan and sub-Saharan Africa)). I see a future scenario for the planet in which we use this information sensibly. I can see the deserts of the planet being potential energy sources. This set against the way we are at the moment our potential energy sources heavily dependent on oil in the same part of the world. We need to remember that we – the rest of the world – are paying 1.7 trillion dollars a year into the countries in the Middles East and North Africa for the privilege of having the oil out of the ground below them. That is a massive distortion on our economies. When we talk about what is going to be the cost to our economy of decarbonising, we fail to take these factors into account at all. There was a war in that part of the world: there still is a war in that part of the world. Stiglitz, the Nobel prize-winning economist, estimated a year ago that the total cost of that war to date to the American economy is $3 trillion. It is said that that war, the second Iraq war, which is costing roughly $3 trillion dollars, was an attempt by the United States (and perhaps Britain), to put in place a friendly government that would secure their oil supplies into the future. So I think we need to look very carefully at people who say the transition from high carbon to low carbon is going to be an expensive process. We haven't thought that through carefully enough. If the United States instead of that action had spent a fraction of three trillion dollars on low carbon energy sources – problem

solved. That would have been a proper investment. The way that money was spent was not an investment at all; it has simply created more problems.

Scientist/Human being

I have recently been challenged on HARDTalk: 'You're a scientist, why are you making comments that are non-scientific?' The answer is because I'm a human being and if you were trained as a lawyer or an economist you wouldn't ask them why they were making comments like that. I was part of the political scene and I think scientists need to come out of the box labelled science. We need to address the problems that we see and we need to face right up to them as we address them in the political scene.

Societies need to respond

I have talked about a paradigm shift and I ought to move more swiftly to a close. To repeat: what we need in that paradigm shift is a collective response of all societies to these problems. If we respond as individual societies the problems will not be solved. This is very clear with climate change. It doesn't matter where the carbon dioxide is emitted, if it's emitted in Africa, we still buy the products and the problem is not solved. We need a completely collective response, which implies global governance at a level we don't come even near to at the moment. Swift ability to act smartly is what is required at the global governance level. Not a 1992 Kyoto agreement that we drag our feet on. In 2010 we are supposed to be into the second stage of Kyoto but we didn't manage the first stage in terms of a global governance process. The United Nations was developed after the Second World War for quite a different purpose - we had two world wars, we wanted to bring an end to that, we had a far-sighted United States president who saw what was needed and set up the United Nations. I believe we might well have a far-sighted United States president again, thank goodness. And we have a far-sighted president in China. If those two people could come together, I do believe we can have these problems solved in a much more manageable way than we have through the United Nations at the moment.

Sustainable consumption

I come to sustainable consumption. The consumerism that drove our economies in the twentieth century so well is a state of consumerism where we have to examine two sides of the word. We consume to improve our wellbeing but the word 'consume' means we're consuming the resources of the planet. We are over-consuming. We cannot manage this even over the next ten, twenty years. We have to switch ourselves into a sustainable culture: a mode of living which is about sustenance. I am suggesting that a 21st Century Renaissance is what is required, a cultural shift into new thinking. It isn't easy to make a cultural shift of this kind. The biggest problem is national perceptions against global priorities. When the United States went to war in Iraq, I think they were concerned about solving a global problem with a national solution. That is not going to be the way forward. Economism, the idea the world's solutions can be solved in an unfettered marketplace, is now out of fashion: long may it stay that way. That sort of economism was based on simple linear geometry or algebra which said "we will always have growth in the economic system and that growth will always be able to produce future solutions". Economist should by now have learnt to stop using that word "always" and yet all of their models are based around that continued economic growth.

Nostalgic romanticism

And finally, we need to tackle nostalgic romanticism. This is a reference to those communities, including the development community, whose approach is to look back in time and say: *"Wasn't it all great in the 1800s, why don't we eschew all of the advances of science and technology and go back to that period of time". This is not the answer.* We need to bring all of our resources to bear to face up to this range of challenges including re-gearing science and technology. It's extremely broad this range of challenges as we come into this twenty-first century set of problems and we really need to bring our resources to bear in a way that we haven't done to date.

Smith School

And now the advertisement for the Smith School. We are establishing something that doesn't look like a university department and I believe it is unique. At the Smith School we bring together academics of the University of Oxford with academics outside Oxford, governments around the world and the private sector to talk about solutions to the problems I've been discussing. How do we take solutions to the marketplace given that decarbonising our economies is going to occur for example? How do we turn that process, not into a risk to your business, but into a challenge for innovation and wealth creation? That's what we're all about. And the red circles around the futures directorate indicate the centres we've already established and the futures directorate, if you know I ran the government foresight process, is a mimic of that foresight process.

Once again a real privilege to be able to pay a tribute to Gareth.
Thank you for that. And you've been a great audience.

This is an edited transcript of the lecture.