Greens and Science:

Why the Green Movement is not anti-Science

Anne Chapman

Green House is a think tank founded in 2011. It aims to lead the development of green thinking in the UK.

Politics, they say, is the art of the possible. But the possible is not fixed. What we believe is possible depends on our knowledge and beliefs about the world. Ideas can change the world, and Green House is about challenging the ideas that have created the world we live in now, and offering positive alternatives.

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We will publish a series of reports and briefings on different subjects. We do not intend to have a party line, but rather to stimulate debate and discussion.

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You can download this publication from
http://www.greenhousethinktank.org/page.php?pageid=publications

ISBN 978-0-9573738-2-2
Print copies of this publication may be bought online from http://www.lulu.com/.

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Green House Post-growth Project

Everyone agrees that we are in the midst of a massive financial and economic crisis. We have suffered the biggest crash since the 30s, and it may get far bigger yet. How ought this ongoing crisis to be understood, and resolved?

There is the mainstream view: we have vast government deficits, and stagnant economies. We have a dire need for economic growth – and a deep-set need for austerity, bringing with it massive cuts in public services.

But what if that diagnosis, which reflects mainstream wisdom, is all wrong? What if the crisis that we are currently experiencing is one which casts into doubt the entire edifice of capitalist economics, which sets growth as the primary objective of all policy? What if the fight between those who say that without austerity first there can be no growth and those who say that we must invest and borrow more now in order to resume growth is a false dichotomy – because both sides are assuming 'growthism' as an unquestioned dogma?

The aim of the Green House Post-growth project is to challenge the common sense that assumes that it is 'bad news' when the economy doesn't grow and to analyse what it is about the structure of our economic system that means growth must always be prioritised. We need to set out an attractive, attainable vision of what one country would look like, once we deliberately gave up growth-mania – and of how to get there. And we need to find ways of communicating this to people that make sense, and that motivate change.

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The author

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Acknowledgments

Some of the material in this report is based on research funded by the Arts and Humanities Research Board, which has been published in *Democratizing Technology; risk, responsibility and the regulation of chemicals* Earthscan, 2007.

I would like to thank my colleagues in Green House for suggestions and comments that have contributed to this report.

Summary

The Green Movement owes a great deal to science, but is sometimes portrayed as anti-science. This is primarily in connection with the opposition of many in the Green Movement to genetically modified food and nuclear power. I argue that this opposition is not an opposition to science, but to these particular technologies.

For Greens technology is political in a way it is generally not for those of other political traditions, because it is the mediator of our practical, material relationship with nature. Technology is part of the world that we share with each other, which helps to make us who we are, so is always of public concern and not a mere private matter. While technology adds material things to the world, science can be regarded as adding knowledge, knowledge that is derived from a systematic, empirical approach to investigation of the world. Science and technology are distinct.

While technology is justifiably a subject of political decision-making, whether the outcome of scientific investigations should be accepted as part of the body of scientific knowledge is not: this acceptance should be a matter only of the extent to which evidence supports the conclusions drawn. However, politics does have a role in setting the framework in which science operates, with regard to the methods that are acceptable, and what it investigates. And science alone cannot be the judge of whether there is sufficient evidence to support a particular course of action.

Scientists and the body of knowledge provided by science provide an important input into public policy and political decision-making. More use could be made of scientific methods, such as randomised controlled trials. However, for many decisions evidence is lacking or unobtainable. In these instances politicians should be bolder in arguing for their proposed course of action on other grounds: for why they think it is the right thing to do.

When it comes to public decisions about technologies the only question that tends to be asked is whether the technology causes harm. Risk assessment is used to provide the answer. Risk assessment is seen by its supporters as the ‘scientific’ way to make decisions about technology. Like the norms of academic science, it requires positive evidence of a causal relationship between a technology and a specified harm. However, the use of risk assessment as the framework for thinking about technology is a political choice, arising from the dominant political and ethical frameworks of liberalism and utilitarianism.

I suggest that Greens oppose technologies such as nuclear power and genetic engineering because they are risky. This riskiness is not simply a matter of the identifiable and quantifiable risks that risk assessment procedures are concerned with. How risky a technology is depends on the extent to which we are ignorant about what its effects may be, and the scale of its possible impacts (even if they are of low probability), not just on what we know about it. Technologies are risky if they are novel (so there is a great deal of ignorance about their

effects) or if catastrophic things can happen if things go wrong.

Greens' arguments against nuclear power and the use of genetic engineering in agriculture are also about the sort of world those technologies bring into being: the nature of the electricity generating system and of farming. These are arguments where scientists have no particular expertise, but ought to be considered in our decision-making about technology.

In conclusion, Greens, like scientists are children of the Enlightenment. Both tend to think that decisions are, or at least should be, made on the basis of rational arguments, by appeal to the evidence. However, Greens are also children of Romanticism. This legacy makes them aware of the limits of science, both in the sense of the limits to its knowledge, and that science is not sufficient to tell us how to live.

I suggest that instead of funding science because we expect it to lead to new technologies, and thus economic growth, science should be funded in two ways:

- Multidisciplinary research focussed on problems that need solving, or issues than need investigation (such as the effects of particular technologies) which brings together a broad range of perspectives and experience (not just scientists) to look at an issue.

- Funding for basic research by scientists who are excellent in their field, to allow them to investigate what interest them and to develop their scientific discipline.

While scientists should be free to investigate and discover, we all have a stake in technology. Many voices need to be heard, speaking from different perspectives on our shared world, if we are to ensure that our technology makes that world a better place.

1. Science and the Green Movement

The Green Movement obviously owes a great deal to science. It is science that has uncovered the threats to our environment of our current ways of living. The impacts of pollution, the threat of climate change, the loss of species, can only be spoken about because of the scientific research that has made them known.

But Greens are sometimes portrayed as anti-science. This is particularly the case in the last 15 years, since the largely successful (in Europe) campaigning of the late 1990s against the use of genetically modified organisms (GMOs) in agriculture. In his book 'The Geek Manifesto', for example, Mark Henderson complains of Greens' opposition to genetic engineering, and also to nuclear power. He considers that Greens have an ideological opposition to these technologies, and that leads them to mis-represent the scientific evidence concerning them.[1] Mark Lynas similarly critiques Greens over these issues, calling the anti-GM movement 'anti-science'.[2]

Now I admit that there is an anti-science strain in Green thought. This is the strain that goes back to the Romantics and complains of the disenchantment of the world associated with rationalism and the development of science.[3] It takes issue with the view of our relationship with nature epitomised by the 'conquer and subdue' aim of the early scientist, Francis Bacon.[4] According to this view the forms of knowledge about nature that science constitutes are antithetical to a right relationship with nature: science is born of a desire to 'subdue reality to the wishes of men' and in this pursuit it is prepared to do things to nature previously regarded as disgusting and impious.[5] Instead, we should appreciate the intrinsic value and spiritual qualities of nature, not regard it merely as material for scientific experiments and as resources for human use.

However, much of this strain of Green thought can be reconciled with science: scientists often do appreciate the intrinsic value of what they are studying and respect its integrity, while they try to understand the mysteries of nature. The critique can be modified to accept science that is done with respect for its subject and which enhances our appreciation of nature. The 'anti-science' attitude complained of by Henderson, Lynas and other recent writers, is, I argue here, a Green opposition to certain technologies. Greens are opposed to particular technologies, and are not 'anti-science'.

In this report I first examine the relationship between science and technology because too often the distinction between them is not clearly made. I then consider the two-way relationship between science and politics: to what extent is it legitimate for political systems to have control over science and how much can or should science, and scientific methods, contribute to decisions on public policy? Finally, I discuss risk and riskiness – because it is as a result of the dominance of risk assessment in the regulation of technology that decisions about technology are seen as matters for science.

2. Science and technology

Elsewhere I have argued that technology is how we build our material world. It is how we add things to that world, and the material things that we use[6] - 'things' being material things themselves, or embodied or realized in material things. The material world that we create with technology is one of the conditions for human life: we are conditioned beings and though it does not determine who we are the world shapes and influences us. The world is also a shared, public thing. Technology, I therefore argue, is always of public concern and is no mere private matter. It is the mediator of how we make use of what nature affords us, of our practical, material relationship with nature. Hence, it takes centre stage for those whose politics is concerned with the impact that the industrialised way of life has on nature. For Greens technology is political, in a way it is generally not for those of other political traditions.

While technology adds material things to the world, science can be regarded as adding knowledge, knowledge that is derived from a systematic, empirical approach to investigation of the world. The diversity of science means that perhaps it makes more sense to talk of 'sciences' rather than think in terms of an integrated whole called 'Science'. Each science has its own methods: sometimes these are based on the classical model of controlled experiments which test hypotheses, but in many disciplines, such as epidemiology, or atmospheric chemistry, investigation proceeds primarily through the collection and interpretation of data – controlled experiments are not always possible, though what data is collected may be informed by hypotheses. In others, such as botany, classification is of prime importance. A science may use conceptual models to understand the domain that it is concerned with, and sometimes laws that give a precise account of what regularly happens can be formulated. These models and laws are not universal, though generally they are consistent with one another. The relatedness of disciplines is revealed when insights in one suggest fruitful lines of investigation in another, but this relatedness does not derive from some logical relationship between the models and laws in the two disciplines, but from the fact that they are both trying to account for the same material world[7]. This account of science explodes the myth of the possibility of complete, perfect, theoretical knowledge – of science as a unified project that, when complete, will explain and be able to predict everything. Abandoning this myth means paying more attention to what happens in the world, rather than trusting to our theory-based predictions of what will happen.

Implicit in much thinking about science, and in particular the justification for public spending on science, is the idea that new scientific understandings will result in new technologies, which in turn will create economic growth. However, historically this was not the relationship between science and technology. Rather the development of tools and machines frequently preceded a scientific explanation of how they work.[8] The Royal Society was established to improve the knowledge of 'all useful Arts, Manufactures, Mechanick practises, Engynes and Inventions' as well as natural things[9]. In eighteenth century France the scientific development of an industry was measured not by whether it made use of scientific theories but by the extent to which it could be explained by science. The scientists were educators of artisans, in the hope that if artisans understood their methods better they would improve them.[10] In Britain there was a similar, though less centrally organized application of scientists to industry: more a matter of personal contacts between scientists and industrialists rather than of government policy. These happened in the coffee houses and pubs of London or philosophical and literary societies in the emerging industrial cities – where scientists, engineers, and businessmen met and discussed scientific and technical issues.[11] In these spaces engineers and manufacturers learned about the latest scientific theories, and sometimes these suggested ways to develop their technology. But also scientists sought to explain manufacturing processes that had been developed independently of science. Manufacturers then used those explanations to improve the processes, while also contributing to the development of science.[12] Though note that sometimes the scientific theory that was most useful for industrial development was not the one that proved to be the most fruitful for advancing scientific knowledge. For example, Josiah Wedgewood owed the improvements he made to the processes of ceramic production to the scientific theory of phlogiston, a theory which was discredited following the discovery of oxygen,[13] and late 18th-century French chemical manufacturers were guided by the theory of affinities, which was scientifically unfruitful, not the then latest theory of combustion.[14]

This sort of science – now mainly engineering science – has of course continued to this day. It has enabled the skill and judgement of workers to be replaced by precise measurement and mechanical control, resulting in de-skilling, automation and its social consequences. However, it is rather eclipsed in government strategies by the sort of science that 'will breed new families of products'.[15] The government here seems to be thinking of something more radical than the gradual improvement in the manufacture and design of products of the type that has been going on for centuries. It wants entirely new sorts of products, presumably based on new scientific knowledge.

Where new scientific knowledge does lead to the development of new technologies there is rarely a simple sequence of the discovery of scientific knowledge followed by its application in new technology – new types of things added to the world. Rather, technology and science are interwoven: the discovery of enzymes that can cut DNA at specific base sequences (restriction endonucleases), and of enzymes that catalyse the synthesis of a strand of DNA using an existing strand as a template (polymerases), were crucial in the development of techniques of DNA replication, sequencing and recombination. However, also of prime importance for the ability to rapidly replicate fragments of DNA (and thus to produce enough copies to enable its sequence to be determined) was the development of the programmable thermocycler, a piece of hardware with which rapid and precise temperature changes can be made in the reaction tube. This allowed the automation of replication methods that used a thermostable polymerase enzyme (one that is not destroyed by the high temperatures required to denature the double helix of the DNA molecule into two strands), leading to a revolution in DNA sequencing.[16] The ability to replicate, sequence and recombine lengths of DNA has led to many further scientific discoveries about the genome and about protein structure. It has also made possible the technology of genetic engineering, which can add things to the world outside the laboratory, those things being organisms whose genes have been modified by direct intervention at the level of the DNA.

Not all modern technological developments and inventions are the outcome of scientific investigation, or the application of new scientific knowledge. Rather they are the implementation of ideas for how artefacts can be improved that arise in the course of practical dealings with artefacts. Such inventions include: cyclone vacuum cleaners, wind-up radios and beakers for toddlers that do not spill their contents when up-ended (such as Anywayup Cups)[17]. The inventors of these practical, useful artefacts were not scientists, but people who engaged in practical activities and reflected on how artefacts could be improved. Their inventions do not make use of any new scientific knowledge, but only of well known and understood principles. The story of James Dyson's development of the cyclone vacuum cleaner is the opposite of the idea that scientific models reveal how something is made up, and thus how to make it. He found the mathematical models of how particles behave in cyclones to be no use at all in designing his cyclone vacuum cleaner because they applied only to situations where all the particles entering the cyclone were of the same size, whereas his cyclone had to be able to cope with particles of all sizes and shapes entering the cyclone at once. Instead he went through a painstaking process of methodically testing prototypes, changing one thing at a time. He argues that the essence of invention lies in this process of iterative development, not in 'quantum leaps' made by individuals of genius.[18] Making things and testing them, not theoretical insights, are what is important in developing new technology.[19]

Where new technology does make use of the insights of recently acquired scientific knowledge, making things and testing them is just as important, because the scientific knowledge on which the technology is based is not a complete account of the world: all any particular science can do is describe one aspect of it, under particular conditions. Whether the technology is going to work in the 'real world' – and how it is going to affect the other components of that world – is not something that can be known a priori. Theory can point to what may happen, and which aspects should be considered, though to give the fullest account, of course, all theories, in all disciplines, need to be brought to bear on the situation, as well as everyday knowledge and common sense, particularly with regard to how people behave. However, even when we have drawn on all the available knowledge something still needs to be tried out in practice before we can be sure that it will work and what effects it will have. This need for a multi-disciplinary evaluation of new technologies which rely on new scientific understandings means that there should be a long lag time between the science and the technology. In contrast, at the moment, the expectation that new scientific insights will lead to new technologies puts pressure on scientists to find applications for the latest scientific research. New technologies are developed prematurely, without proper research into the impacts those new technologies will have. As well as the policies of research councils, the involvement of business in funding university science research drives this search for applications. Funding by business means that the applications developed are those that the businesses can make profits out of, which are not necessarily the applications which are of most benefit to society as a whole. In addition, where research into effects of new technologies is funded by those with a commercial interest in that technology, the reported results tend to down play the negative impacts and exaggerate positive ones.[20]

Because science and technology are different activities they answer to different norms and we use different criteria when judging them: how we judge whether or not the outcome of a scientific investigation should be added to our stock of knowledge about the world is quite different from how we judge a technology. With regard to the former we ask questions about the extent to which evidence supports the conclusions drawn. Of course the answer is rarely a simple yes or no, and it is may be reasonable to require stronger evidence in some cases than in others, depending on judgements about the implications of that knowledge for a body of scientific thought. With regard to technology there is a much wider array of questions that should be asked: how will it affect individual agency and social relations, how risky is it, and how useful? In essence, will it make the world a better place for human life? Technology is a shared thing: individual decision-making is rather a myth as once others have and use a technology it is difficult for an individual, or organisation, to decide not to use it and still be a part of society. Decisions about technology should therefore be made in the same way as decisions that affect other aspects of the public realm: through a political process, and through consideration of the public interest. Leaving these decisions to 'the market' means that it is the dominant private interests of the day (at present large multi-national corporations) that decide which technologies should be developed and deployed.[21]

It is because this distinction between science and technology is generally not made in policy debates that those who object to technologies which arise from scientific research end up being branded as 'anti-science'. For example, around the time of the debates about genetic engineering in agriculture in the late 1990s, the House of Lords Select Committee on Science and Technology produced a report which was concerned with the processes whereby positions are taken on issues such as nuclear waste and GM food. However, these were seen as a matter of the relationship between 'Science and Society' – the title given to the report.[22] A government consultation on the 'biosciences' was not about sciences such as biology, zoology, biochemistry, genetics, *etc.* but matters such as cloning, genetic testing and genetically modified crops.[23] These are technologies, made possible by advances in our knowledge within biological sciences, they are not the sciences themselves. Opponents of genetically modified food are not opponents of genetic science.[24]

3. Science and Politics

I have argued above that decisions about technology should be made by a political process according to what is in the public interest. What about science? Is science independent of politics? My answer to this is yes and no. With regard to whether a result from a scientific investigation should be accepted as part of the body of scientific knowledge science is independent. What matters is the extent to which a conclusion is supported by the evidence: there is no place for political control, influence or ideology. However, this is not to argue for the complete autonomy of science as a practice. There are at least three arguments in favour of the public and the political process having a say with regard to the practice of science.

Firstly, the technology used within science to gain knowledge, technology that constitutes the world of the laboratory, is of legitimate public concern. The pursuit of knowledge is not a justification for the use of any method whatsoever. Thus there are controls over the use of laboratory animals in experiments and over investigations in which human beings are the objects of the research. These controls are intended to prevent the unjustified use of animals and to ensure that the rights of the human subjects of experiments are respected. We perhaps also should be concerned about the world of the laboratory because it may be an anticipation of the 'real' world outside it, if technologies used there then find wider application.[25] Concern over the methods of science are also justified where the effects of those methods are not confined to the laboratory. Testing things out - as objectors to nuclear weapons tests and farm scale trials of genetically modified crops have made clear - involves actually doing them; exploding the bombs, or growing the crops, and thus causing the effects that are being investigated.

Secondly, science cannot be the judge of whether scientific investigation has provided sufficient evidence to support a particular course of action, or what the burden of proof should be. That judgement involves evaluation of the possible consequences of alternative actions, including that of non-action, and of non-consequentialist reasons for and against the course of action - an evaluation that is not the job of science. The practical acceptance of knowledge, in the sense of acting upon it, is therefore not a matter for science alone. So, for example, the European Commission rebuked a group of its scientific advisers for publicly disagreeing with its decision to ban the use of phthalate softeners in certain baby toys. The scientists on a committee that advised on phthalates did not consider that the evidence of harm was sufficient to warrant a ban, but the Commission retorted that this decision was not one for the scientists to take.[26]

What the burden of proof should be depends on the institutional setting in which science is used.[27] Within the institutional setting of academic scientific research, the standard of proof normally required is equivalent to the 'beyond reasonable doubt' standard of criminal cases: just as it is more important that the innocent are acquitted than that the guilty are found innocent, it is more important that propositions are not accepted as true when they are not, than that they are (provisionally) rejected when they are true. The aim is to avoid adding erroneously to accepted knowledge. The result is that epidemiological studies or animal tests on the toxicity of chemicals are only considered to provide 'statistically significant' results if the probability of a false positive is less than 0.05. However, Cranor points out that if this data is evidence in civil cases, or used for regulatory purposes, this standard of proof is inappropriate. In civil cases, for example, a case only has to be proved on the 'balance of probabilities', equal weight being given to both sides of the dispute. This means designing tests and analysing data to give as much weight to guarding against false negatives as against false positives.

Thirdly, science cannot decide what it is worthwhile to know, and thus to what ends scientific investigation should be put. Whether it is worthwhile knowing something depends on its meaning in the context of human life in the world. In *The Life of the Mind* Hannah Arendt makes a distinction between the process of cognition, which leads to knowledge, and the process of thought, which leads to understanding of what something means. The process of cognition 'leaves behind a growing treasure of knowledge that is retained and kept in store by every civilization as part and parcel of its world'[28]. In contrast, the understanding of meaning is intangible and never final. Thinking and understanding do play an important role in science, but here they are means to an end, the end being the type of knowledge sought. Science may seek knowledge of something because that knowledge would resolve problems and questions internal to the science, but ultimately the meaning of scientific knowledge has to involve reference to things and concerns that are external to science. At that point science is not the judge of what it is worthwhile to know.[29]

Thus there are grounds for political control over what science investigates, the methods of investigation it uses, and whether action should be taken as a result of those investigations. However, a finding of science should not be rejected because it is at odds with a political ideology, or other belief: whether to accept or reject a scientific finding should always be a matter of whether or not the evidence supports that finding. In contrast there should be political debate about and control over technologies, and those debates need to encompass a wide range of perspectives, not just 'scientific' ones.

The relationship between science and politics is not just one way. Politics sets the framework in which science operates; and scientists, and the body of knowledge provided by science, influence politics and public policies. The power of science is shown by the reliance of ministers on 'scientific advice' when making decisions about the regulation of technologies, drugs, health, energy policy and much else. There is now a scientific advisor in every UK government department and ministers are generally keen to show that their decisions are 'evidence-based'. Whether this is really the case, or whether politicians are in fact simply finding evidence to fit their policies, and ignoring evidence to the contrary, is a moot point. Mark Henderson, in his recent book, *The Geek Manifesto,* describes a number of instances where this seems to have been the case.[30] While arguing for 'evidence-based' policy Henderson recognises that scientific evidence does not determine policy: questions of ethics, politics and economics are also important. Perhaps what we in fact need is more open debate about these other factors in decision-making; politicians who argue for the policy they want on the basis that it more appropriately allocates responsibilities, protects liberty, or provides justice, in short because it is the right thing to do, rather than because the evidence shows that it will have a particular outcome, when that evidence is questionable at best, and may be unobtainable. In politics decisions generally have to be made without the benefit of knowing exactly what the consequences of those decisions will be.

One of the things that Henderson calls for is more use of randomised controlled trials of policies. Policies in areas such as education and crime prevention, for example, should be tested in the same way as are new drugs. Just as new technologies need to be tried out and tested because we do not have a complete account of the world and therefore cannot know beforehand whether something will work, or what its effects may be, our theoretical knowledge is insufficient to be sure whether a particular intervention will achieve a particular public policy outcome. "We should recognise that confident predictions about policy made by experts often turn out to be incorrect".[31]

While not denying that randomised controlled trials may be useful in some instances the way of thinking associated with them does have its dangers. One is a narrow focus on achieving measurable outcomes, thereby missing a great deal else that is going on. Because we are multi-dimensional beings (we are biological organisms, social and moral beings) everything we do can have a number of different descriptions. For example, the farmer does not just produce food but may also be polluting the water supplies, or maintaining the countryside; the doctor is caring for her patient, developing medical knowledge, performing a role within the institution of the hospital, and earning her living. 'Unintended side effects' are a result of not being aware of all these different possible descriptions of what we are doing, of a focus on just one thing. It is important therefore that randomised controlled trials generally consider more than one outcome, and do not limit their evaluation to things that can be easily quantified and measured. They should look for side effects. For example, programmes to get people into work should not just look at the outcome of numbers in paid employment after a certain time period, but whether those involved felt more in control of their own lives, more able to make decisions, and contribute as citizens. Trials of policies should consider what virtues and values they promote, not just whether they achieve a particular defined outcome.[32] And we have to accept that in many instances conducting randomised controlled trials will not be possible, and yet decisions will still have to be made.

4. Risk and riskiness

In the mid-1980s a new disease appeared in British cattle. Cows staggered around, with uncoordinated, jerky movements; they lost the ability to stand up and ultimately died. In 1987 it was officially recognised as bovine spongiform encephalopathy (BSE), but it was commonly called 'mad cow disease'. After investigation it was considered that the most likely cause was feeding cattle protein supplements which contained the ground up remains of sheep and cattle offal. For ten years government maintained that this new disease would not spread to humans who ate beef: 'British beef is safe' was the message of the agriculture minister, John Gummer, who famously fed a beefburger to his four year old daughter, and of the government's chief medical officer, Sir Donald Acheson and his successors. Then, in 1996, the health secretary, Stephen Dorrell stood up in the House of Commons and announced that consumption of beef infected with the agent which caused mad cow disease was the most likely cause of a new disease in humans, variant Creutzfeldt-Jakob disease (vCJD). Following this announcement many countries banned British beef and its price halved. To date, at least 280 people have died of vCJD, 176 of those in the UK.[33]

It is against this background that public reaction to government reassurances a few years later, that 'GM food is safe', should be understood. Scientists did not really know that eating BSE-infected cattle would not cause a similar disease in humans. Perhaps they thought it unlikely, but they did not understand the disease or its causes, so they could not really know. Perhaps they thought it best not to alarm the politicians or the public by admitting this ignorance. Perhaps it was the influence of the norms of academic science – that a proposition (eating BSE-infected beef can cause disease in humans) should be rejected unless and until it can be proved beyond reasonable doubt, or at least that there was good evidence for it. It was the positive causal relationship that had to have evidence to support it, not the proposition that eating infected beef did not cause disease. So with GM food, how could the scientists know that such a novel technology, which many people saw as 'tampering with nature' was safe. The absence of evidence of harm could not be sufficient.

Genetic engineering of our food, like nuclear power, is opposed by Greens (an opposition which I suggest is shared by most of the public) because they see it as risky. This riskiness is not a matter of the probability of occurrence of specified, known, types of harm – risk as conceived by technical risk assessments. Such technical risk assessments require the type of harm to be identified and an assessment made of how likely it is to occur. The dominance of risk assessment in our approach to technology is one reason for the central role that science has in decisions about technology. Risk assessment is seen by its supporters as the 'scientific' way to make decisions about technology. Like the norms of academic science, it requires positive evidence of a causal relationship between a technology and an unwanted outcome – the harm.

However, the use of risk assessment as the framework for thinking about technology is a political choice – there is nothing inherently scientific about it. Risk assessment is used because of the dominance of the ethical and political philosophies of utilitarianism and liberalism. Utilitarianism prescribes that what matters is harm to individuals (humans, and perhaps other sentient animals), and that we should make decisions on the basis of what results in the best overall balance of harms and benefits. The central tenet of liberalism is that individuals should be free to live how they want as long as they do not cause harm to others: the state should only interfere in the actions of individuals if those actions cause harm to others ('the harm principle'). Hence the focus on whether a technology causes harm and the 'body count' approach: the arguments about how many people have or have not been killed by genetic engineering, or by nuclear power as opposed to coal mining. And the attempt to regulate synthetic chemicals through the impossible task of trying to predict the harm that any particular chemical may do (see Chapman, 2006 for the multiple uncertainties of chemicals risk assessment). What is omitted from both utilitarianism and liberalism is the idea of a world that matters, which is shared by everyone, which we inherit from the past and bequeath to the future. Decisions about technology, which forms part of that world, should be collective decisions, made on the basis of considering whether a technology will make that world a better place, not simply on the basis of whether the technology will cause particular harms to individuals.

Identification of risk, as carried out in technical risk assessment, requires positive knowledge that an outcome, considered to be harmful, is probable. If no harmful outcome can be identified then there is no risk. In contrast, a situation or technology is risky if we know little about it, even if we cannot identify what harm it may cause, because for all we know, harm is possible. It is not a matter of probability, but what is possible in this epistemic sense, *i.e.* taking into account the extent of our knowledge, and ignorance. Hence novel technologies where we are relying on (inherently incomplete) theoretical scientific knowledge are risky. Critics such as Mark Lynas argue that this attitude is an example of the "naturalistic fallacy – the belief that natural is good, and artificial is bad". Lynas goes on to argue that "this is a fallacy because there are plenty of entirely natural poisons and ways to die".[34] But caution with regard to 'unnatural' technologies does not imply a belief that all natural things are good and benign.[35] There are natural poisons, but we have been dealing with them for generations and have learned a great deal about how to avoid or cope with them.[36] We know what they can do. The fact that nature is not always benign is not an argument for using a novel technology that may disrupt natural systems and processes in ways that we cannot predict. Nassim Taleb puts it like this: "What Mother Nature does is rigorous until proven otherwise; what humans and science do is flawed until proven otherwise."[37]

Whereas risk refers to an outcome, the riskiness of a situation or technology is inherent in the technology or situation itself. Identification of risk requires prediction: we need to know and be able to predict the probability of the other conditions that are needed for the outcome in addition to the technology: as well as a mussel contaminated with radioactivity from the discharge from a nuclear power plant, we need to know whether people will collect and eat that mussel, and if so how much, how often, and what other radioactivity they are exposed to; it is not a matter simply of the presence of a carcinogenic chemical in a product, there must be a pathway by which it can enter the human body, and a known probability that once there it will cause cancer. In contrast, the riskiness of something is a property of the thing itself. A chemical can be identified as risky if we know it has the potential to cause harm – we do not need to be able to predict exposure levels and whether harm will actually occur.[38]

Technical risk assessment tends to consider probability and size of harm together, as if the two were commensurable: a low probability of a large amount of harm comes out as equivalent to a high probability of a small harm – they both give the same number of 'deaths per year'. But high impact/low probability outcomes are of much more concern that low impact/high probability ones. Events that cause some harm, but are not catastrophic can strengthen a system (Nassim Taleb has coined the term antifragile to describe this sort of system[39]). High impact, catastrophic events wipe it out.

Debates about the regulation of technology amongst public policy experts tend to focus on risk versus precaution.[40] Risk assessment approaches are considered to be 'evidence based'. Precautionary approaches take action where there is a lack of clear scientific evidence: where there is uncertainty and ignorance. A recent publication of the European Environment Agency gives the following rather long-winded working definition:

"The precautionary principle provides justification for public policy and other actions in situations of ***scientific complexity, uncertainty and ignorance****, where there may be a need to act in order to avoid, or reduce, potentially serious or irreversible threats to health and/or the environment, using an* ***appropriate strength of scientific evidence****, and taking into account* ***the pros and cons of action and inaction*** *and their distribution."*[41]

Precautionary approaches do not disregard evidence, rather they are more open to different types of evidence than the often narrow view taken by risk assessment. They consider the 'weight of evidence' – the evidence from different, independent sources, which together may form a convincing case, though none individually is conclusive. It also takes into account areas of ignorance and considers the potential consequences of that ignorance. I suggest that what precautionary approaches are concerned about is what, in everyday language would be called how risky something is.

Nuclear power is obviously risky. It is not a matter of the number of people it has or has not killed but the fact that it requires elaborate safety systems and armed guards at nuclear power stations. There is also the massive unknown of how we are going to keep safe, for centuries, all the radioactive waste it generates.[42] No coal mining accident has resulted in the exclusion of people from a 20km radius, as has recently happened at Fukushima. That exclusion represents the loss of the home and community for about 100,000 people, possibly for decades.[43] This is qualitatively different from deaths in mining accidents. Deaths of miners, while devastating for their families, do not constitute the destruction of a whole community, and may lead to the strengthening of mining communities (though this is not to say that mining deaths are a good thing).

Genetic engineering is risky because it is attempting to produce organisms with new characteristics by introducing genetic material from other species, when there is a lot we do not understand about genes and how they work.[44] Synthetic chemicals which do not occur in nature, but are made in factories and put into consumer products, and then get into our bodies, the rivers and the air, are risky because we do not (and probably cannot) understand the effects they may have, on our bodies, the health of wildlife, or the functioning of geochemical systems.[45]

With genetically modified organisms there is a fear that once the organism has been released into the environment it will be impossible to get it back: plants and animals reproduce and spread and are not easily contained. The introduction of a genetically modified organism could therefore be an irreversible step. Again there is a concern about catastrophic consequences, not the probability of quantifiable known harms. For synthetic chemicals we know that some have had devastating effects that could not have been predicted. The classic example is chlorofluorocarbons (CFCs), invented in the 1930s as a non-toxic, non-flammable refrigerant. They do not occur in nature. Decades later it was discovered that that their stability, the property which made them so good as refrigerants, meant they accumulated in the upper atmosphere where they reacted with the protective layer of ozone, destroying it in the process. The importance of the ozone layer was not understood when CFCs were invented. And anyway, who would have thought to ask an atmospheric chemist about the safety of a refrigerant?[46] A more recent example is the drug diclofenac (another non-naturally occurring organochlorine compound, which was invented by Ciba-Geigy (now Novartis) in 1973). It was used for decades as an anti-inflammatory drug to treat humans but from the 1990s it was given to cattle in India, then Pakistan, as a pain killer. It has wiped out over 95% of the vulture population (vultures feed on the carcasses of fallen cattle), and resulted in multiple problems of rotting carcasses, feral dogs and disease.[47] No regulatory regime requires new synthetic chemicals to be tested on vultures.

Green objections to these technologies are not objections to science. They are objections to an over-confidence (which perhaps scientists working on a technology do tend to have) in our ability to predict consequences, control events and not make mistakes. The official report on the Fukushima disaster said that it was

"a disaster 'Made in Japan.' Its fundamental causes are to be found in the ingrained conventions of Japanese culture: our reflexive obedience; our reluctance to question authority;

our devotion to 'sticking with the program'; our groupism; and our insularity."[48]

The tsunami of 2011 was a natural phenomenon, but the problems at the Fukushima nuclear power station were man-made. No one was responsible for the tsunami, but people were responsible for the failures at Fukushima. This difference means the two cannot be compared. Fukushima cannot be excused by pointing to the death toll of the tsunami, just as harm caused by synthetic chemicals cannot be justified by the fact that some natural chemicals are toxic.

Japan is a country that prided itself on its engineering and technological expertise. It pioneered quality control and the building of cars which did not break down. If there can be a disaster at a nuclear power station in Japan, who are we to say that there are no waiting disasters "Made in Britain", or in France, or Germany. Perhaps things would unfold differently here, but I am sure that there are plenty of defects in the British way of doing things that could lead to a similar disaster. Fairlie and Parkinson conclude that

"perhaps the simplest of the lessons to be learned from Fukushima is that nuclear power is a supremely unforgiving technology. When things go wrong, they can go very wrong with consequences that are extremely difficult to remedy, even in advanced industrial nations".[49]

Fairlie and Parkinson go on to point out that "nuclear power is merely a complicated way of boiling water". This brings us to the issue that if we are going to use risky technologies there have to be good reasons for doing so, and alternatives need to be fully examined. This is the Green movement's critique of nuclear power: it is risky and there are alternatives available. We could make a really serious effort to reduce our energy use, and we could invest in renewable energy and energy storage, rather than in nuclear power stations. Similarly with genetic engineering in agriculture: Greens argue that risky GMOs are just not needed. Plenty of food is produced for the world's population, the issue is that a lot of it is wasted, some people have too much, and others do not get access to it. These problems will not be solved by genetically modified organisms.[50]

5. Technology and the World

Another line of argument in the Green movement against nuclear power and genetically modified food is concerned with the power relationships associated with these technologies. Nuclear power is a large scale, centralised, inflexible way of generating power, owned by large corporations or state-owned companies and guarded by armed security forces. The scale of the hazards associated with it legitimates authoritarian enforcement of rules, which in turn erodes civil rights.[51] In contrast renewable energy generation can be decentralised: owned by individuals and small communities, increasing their economic independence. A common concern with genetically modified crops is the role of the large corporations who develop and own it, and retain intellectual property rights over the seeds that they sell to farmers. Arguments about genetically modified crops are part and parcel of arguments about who has control over the food system and the nature of farming. Do we want large scale, capital intensive agribusiness, or small scale mixed family farms?

These are arguments about the type of world a technology brings into being. They are not ones that scientists who work on nuclear power or genetic engineering have any particular expertise in. They are properly matters for public political debate and 'risk assessment' needs to move out of the way in our thinking about technology to make space for them.

6. Conclusions and Recommendations

Like scientists, Greens are children of the Enlightenment. Both tend to think that decisions are, or at least should be, made on the basis of rational arguments, by appeal to the evidence. However, Greens are also children of Romanticism. This legacy makes them aware of the limits of science, both in the sense of the limits to its knowledge, and that science is not sufficient to tell us how to live. Science is not enough.

But science is important, as is not distorting or lying about evidence. However, it should be recognised that in many areas of public policy good evidence is lacking, and may be unobtainable, yet decisions still need to be made. Those decisions should be defended by reasons other than evidence. Politicians should not be afraid of making arguments based on justice and fairness, or the need for transparency or accountability, or that a particular course of action promotes particular values and virtues.

Public funding of science is currently justified in good part by the expectation that new scientific insights will lead to new technologies. Scientists are encouraged to seek to develop those technologies, and enter into partnerships with business to bring those technologies to 'the market'. This leads to attempts to find applications for the latest scientific research, perhaps prematurely, and without research into the impacts that new technologies will have.

Instead we should fund science in two ways. Firstly, we should fund multi-disciplinary research that is focussed on problems that need solving, or issues that need investigation (such as the effects of particular technologies). This research should bring together scientists from different disciplines and non-scientists from relevant walks of life, so that a broad range of perspectives and experience is brought to bear on an issue. There should be a high level of public involvement with and consultation about this research. It should not be dominated by business interests.

Secondly, there should be public funding of basic scientific research, with funds given to those scientists who are excellent in their field to investigate what interests them and to develop their scientific discipline. This research should be part of educational institutes, and done for cultural as much as economic reasons.

For both types of science the technologies and methods used should be within boundaries set with input from the public and expertise external to science.

Sometimes, of course the two types of inquiry will interact. The results of basic scientific research may be useful in solving a particular problem. It may lead to developments in technology. But those developments always need to be evaluated by multi-disciplinary research programmes and not seen as the preserve of just one area of science. Scientists should be free to investigate and discover, but we all have a stake in technology. Many voices need to be heard, speaking from different perspectives on our shared world, if we are to ensure that our technology makes that world a better place.

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Endnotes

[1] Henderson 2012: chapter 9
[2] See for example Lynas, 2013.
[3] See for example Scott Cato:17.
[4] Francis Bacon (1561-1626) was a statesman and philosopher generally credited with founding empiricism – a systematic approach to studying nature using inductive reasoning. He wanted to understand nature in order to 'conquer and subdue' it. (Robertson, J.M. (ed) (1905):843.)
[5] Lewis, 1943.
[6] See Chapman 2004 and Chapman 2007:25.
[7] This account of science is indebted to Nancy Cartwright and other philosophers of the 'Stanford School' – see Cartwright 1999, Dupré 1993 and Dupré 2001.
[8] See (Nye, 2006:10).
[9] Hall, 1981:132.
[10]Gillispie, 1957.
[11] Hong, 1999:298.
[12] Schofield, 1957.
[13] McKendrick, 1973.
[14] Gillispie, 1957:404.
[15] See for example DTI, 2000: Executive Summary, paragraph 2.
[16] Dale and von Schantz, 2002:143-148.
[17] For the story of the cyclone vacuum cleaner see Dyson, 1997. The wind-up radio was invented by Trevor Baylis, a swimmer, swimming-pool manufacturer and stunt man – see http://en.wikipedia.org/wiki/Trevor_Baylis. For information about Anywayup Cups see http://www.mandyhaberman.com.
[18] Dyson, 1997:112-113 and 168-169.
[19] Nassim Taleb makes this point in his book, *Antifragile* (Taleb, 2012, Chapters 13 and 15). He argues that most new advances in technology are the result of 'trail and error tinkering', not the application of theoretical insights.
[20] See Langley and Parkinson, 2009 for a critique of the involvement of corporations in UK science.
[21] I realise here that there are dangers of over-control, of a central planning approach and the stifling of innovation. This is not what I intend. I do not want the Dyson's of the world to be stopped from improving vacuum cleaners or hand dryers. However, I do think the political realm should assume responsibility for technologies, and set parameters within which innovators can work, rather than risk of physical harm being the sole rationale for public controls over technology. This is not the subject of this report, and I refer the interested reader to Chapter 10 of Chapman 2007.
[22] House of Lords Select Committee on Science and Technology, 2000.
[23] DTI, 1998.
[24] For example, Friends of the Earth, which campaigned against GM food, welcomed the 'biomedical revolution', including the sequencing of the human genome, for the insights it will give into the effects of chemicals on the human body. See Friends of the Earth, 2000.
[25] Arendt, 1978:57.
[26] ENDS Environment Daily, Friday 26th November 1999.
[27] The arguments here are from Cranor, 1993.
[28] Arendt, 1978:62.
[29] Arendt, 1978:54.
[30] Henderson 2012:46-56.
31 Haynes, Service, Goldacre, and Torgerson, 2012 p.15.

[32] The importance of strengthening intrinsic values, such as self-acceptance, care for others, and concern for the natural world has been highlighted by the Common Cause project. See Crompton, 2010.
[33] For an outline of the BSE story see Sample, 2007 and http://en.wikipedia.org/wiki/Bovine_spongiform_encephalopathy (consulted on 23/1/13).
[34] Lynas, 2013.
[35] For an exposition of the 'unnatural' argument against genetic engineering see Chapman, 2005.
[36] Some have argued that we know more about novel synthetic chemicals than we do about natural ones because the former have been subject to much more scientific investigation (see Ames & Gold, 1990). This argument firstly does not recognise the huge limitations of the knowledge that scientific investigation provides us with, and undervalues the experiential knowledge we have of natural chemicals: even if we cannot identify what natural chemicals have what effects, we do know that the effects of natural chemicals are those we have already encountered – they are already with us and we have learned to avoid or cope with them, at least to some extent, though we can always learn more.
[37] Taleb, 2012:349.
[38] In Chapman 2007, p. 103-112 I discuss other aspects of chemicals, in addition to their known capacity to cause harm, which make them 'risky'. My concept of riskiness has similarities with Nassim Taleb's concept of fragility – see Taleb 2012. Dangerous is also a relevant concept: fast moving traffic on a road is dangerous to pedestrians, but pedestrian casualties can be reduced by preventing pedestrians getting on to the road. The risk (in terms of probability of pedestrian casualties) would be reduced, but the traffic would be just as dangerous. Trying to cross the road would be just as risky.
[39] Taleb, 2012.
[40] See Chapman, 2007: 74-75 for an account of the battle lines between the EU and the USA on chemicals legislation for an example of how the approaches are framed in terms of risk and precaution.
[41] Gee, 2013:681.
[42] Aside from the risks associated with the long term storage of waste from the nuclear industry, there are the costs. For example, a report by the UK House of Commons Public Accounts Committee in February 2013 criticised the ever rising costs of dealing with the UK's legacy of nuclear waste at the nuclear fuel reprocessing plant, Sellafield: "Deadlines for cleaning up Sellafield have been missed, while total lifetime costs for decommissioning the site continue to rise each year and now stand at £67.5 billion". Currently £1.6 billion a year of public money is spent at Sellafield, at a time when the UK's public finances are under severe pressure.
[43] Fairlie and Parkinson, 2012.
[44] See question 4 of Tudge 2012 for a good summary of all the unknowns in genetic engineering.
[45] See Chapman 2006 for the impossibility of the task set by the risk assessment of chemicals.
[46] A review of the history of our understanding of the effects of CFCs on the ozone layer considered that a conventional risk assessment in the 1960s would have concluded that there were 'no known grounds for concern' (Farman, 2001).
[47] The increase in rabies following the rise in the number of feral dogs is thought to have caused the death of 50,000 people (Walker, 2008). See also Oaks *et al*, 2004 for how diclofenac was identified as the cause of the precipitous decline in the vulture population.
[48] The report is available at: http://reliefweb.int/report/japan/official-report-fukushima-nuclear-accident-independent-investigation-commission (accessed on 1/2/13).
[49] Fairlie and Parkinson, 2012.
[50] See Tudge, 2012 for a recent example of this argument.
[51] See Beck, 1992, p.80.