19th Campden Day Lecture

What biotechnology can do for the food industry

Professor Derek Burke

Professor Derek Burke, CBE, DL, BSc, PhD, Hon ScD, Hon LLD, is a highly distinguished scientist. A graduate of the University of Birmingham, where he also obtained his PhD, he held a number of senior academic appointments in the UK and North America before becoming Vice President and Scientific Director of Allelix Inc in Toronto. He relinquished this position in 1987 upon his appointment as Vice Chancellor of the University of East Anglia: a post he held until his retirement from academic life in 1995.

He has been, and remains, particularly active in public life. He has been a member of the Government's Technology Foresight Steering Group, whose influential reports have encouraged business people, scientists and engineers to envisage and realise future developments. He remains a director of the Cancer Research Campaign and a member of the Biotechnology and Biological Sciences Research Council and of a number of learned societies, professional bodies and local charities.

As Chairman of the Advisory Committee on Novel Foods and Processes, since its reconstitution in 1988, he is responsible for advising the government on issues relating to the manufacture of novel foods or foods produced by novel processes. He has, therefore, had direct contact with the rapidly developing area of food biotechnology that is the subject of his Campden Lecture.

CAMPDEN DAY LECTURE

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by Professor Derek Burke

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In this lecture, I want to describe some of the recent developments of biotechnology that are being applied to the modern food and agricultural industries, to comment briefly on some of the social, ethical and religious issues that arise from its use, and in the light of these, suggest ways in which applications may develop in the future

I shall define biotechnology as 'the application of biology to human use' and then distinguish, in this broad definition, 'old' from 'new' biotechnology. By 'old biotechnology', I mean a series of technologies that have been in use since we ceased to be hunter-gatherers. These include:

- Fermentation, for the production of fermented drinks, such as beer and wine, and foods, such as bread, sauerkraut and such delicacies as Swedish fermented herrings!

- Plant breeding, extending from the dawn of agriculture, in the breeding of corn for example, right up to the present day, in the production of modern high-yielding wheat strains, for example, the short-stalked varieties.

- The use of enzymes in food processing, for example the use of an extract of the calf's stomach (containing the enzyme chymosin) in cheese processing.

Then there are a number of 20th Century developments, such as:

- A fermentation process for the production of acetone, for use in explosives, developed during the First World War.

- Another fermentation process, using deep vat fermentation, that was developed for the production of penicillin in the Second World War.

But 'new' biotechnology derives from techniques discovered only in the last 20 years. Briefly they are:

- The ability to cut and stitch DNA. That is, the use of restriction enzymes to cut DNA into gene-sized pieces, to insert this mixture into bacteria and to use the growth of the transformed bacteria, followed by separation of the bacterial clones, to amplify and separate the many, many different DNA pieces; the sequencing of each of these pieces by a mixture of chemical and biochemical

techniques; and then the ability to reinsert any of these pieces into another DNA genome.

- The ability to move DNA and genes from one organism to another, and moreover the ability to persuade that new gene to work, that is to bring about protein formation, in this new organism. This is possible because, rather broadly, the way genes work is universal, from bacteria to man. These two techniques are what is called 'genetic engineering' or 'genetic modification'.

- The ability to modify proteins by a process termed 'protein engineering'. This involves systematic manipulation of the amino acid sequence of a protein, thus altering the properties of a protein, such as the enzyme in washing powder, by working at the level of the DNA. In other words, altering the sequence of the DNA to alter, in turn, the sequence of the protein.

The ability to move genes from one organism to another, and to make them work in the new organism, is the basis of new biotechnology, a pervasive technique now spreading rapidly through the pharmaceutical, chemical, agricultural and food industries. For example, foreign genes can be transferred into bacteria so that they will produce high-value, low-volume substances such as growth hormone, insulin or interferon. They may be transferred into plants to introduce herbicide or pesticide resistance, or to modify the plant's mating system so that high-yielding F1 hybrids can be produced. Foreign genes may also be transferred into animals to produce transgenic animals, which are already being used to produce high-value, low-volume proteins for pharmaceutical use.

The application of some of these developments is obvious; growth hormone can now be used that is free of contamination with the agent for the Creutzfeldt-Jakob syndrome, and the supply of insulin for diabetics or of interferon for patients with Hepatitis B is no longer limited. Farmers will be able to use less herbicide in raising crops such as soya, and farmers need no longer lose 5% of their corn crop to a worm. The world's population is going to double in the next 40 years, or to put it another way, 250,000 new mouths are born every day. And how are we going to feed them? biotechnology is part of the answer.

The techniques are also being used to characterise the differences between similar, but not identical, plants or animals, and to link the presence of certain genes, as shown by molecular biology techniques, with particular traits. Using this technique, it is not necessary to wait until the animal or plant comes to maturity to know whether it shows a particularly desirable characteristic or not, for that can be determined at the embryo stage. This technique is greatly speeding up breeding experiments. Very recently it has been discovered that all the cereals, wheat, oats, rice, etc., have a similar genetic lay-out, and so information from one species can be directly applied to another. This is a huge step forward in plant breeding.

Most of the genes that I've described so far have been structural genes: genes that determine the structure of a particular protein. But recently other genes, genes that control development, have been isolated. For example, the genes that control flower shape and colour in the snap-dragon. This means that we can start to manipulate flower shape and colour for the horticultural industry. More importantly, the genes that control the plant's response to day length have been isolated. This means that it may be possible, by modifying these genes, to produce plants that come to maturity more quickly, and so push north, for example the northern limit for growth of rape in Canada, with a huge economic impact.

Products from Biotechnology come to Market

So what is on the market? One way of measuring this is to look at what products have been approved for sale in Britain This approval is the responsibility of the Advisory Committee on Novel Foods and Processes, which I have chaired for the last nine years. In that time, we have approved just over 50 products, 16 of which have been products of genetic modification. It might be useful to briefly summarise them, as follows:

Foods obtained through genetic modification

- enzymes such as chymosin, from three different sources
- oils from genetically modified crops such as rape, maize and soya
- tomatoes and tomato paste
- herbicide resistant crops such as soya and rape

Non-genetically modified novel foods

- mycoprotein
- speciality oils
- modified fats and sugars
- novel cereals such as lupin
- micro-organisms such as *Lactobacillus*

Most of the public's attention has concentrated on the foods obtained through genetic modification, and it is in this area that we have had most to learn.

It is worthwhile tracing the way biotechnology has led to product development, because that will help us extrapolate into the future. The first products to be developed were high-value/low volume products for the pharmaceutical industry; products of single structural genes such as growth hormone, insulin and interferon. These, and a number of similar products, are now in routine production using a variety of cell systems, bacterial, insect and animal, in large volume fermenters. All that is necessary is to isolate the structural gene, although if it isolated from the genome of higher organisms, it may be necessary to remove the introns, those internal nucleotide sequences that are not translated. It will also normally be necessary to modify the signals found upstream in the DNA sequence from the structural gene that are responsible for switching on and enhancing the activity of the gene.

The next step was to use synthetic genes, for these can now be synthesised routinely once the nucleotide sequence is known. The first useful gene to be synthesised was, I believe, chymosin, which was synthesised by several companies in the early 80's, and several such chymosins are now on the market for use in cheese curing. The cheeses made in this way were offered, by the Co-op initially, as suitable for vegetarians, and carry a V label; the first example of an real customer advantage from a genetically modified product. The big advantage of such synthetic genes is that the DNA sequence can be modified at will. Sometimes this is done to optimise the codon usage, that is to change the precise sequence of the three nucleotides in a codon in order to increase the efficiency of product formation in a different host organism. This approach can also be used to systematically alter the amino acid sequence of a protein, keeping the biological activity but changing other properties, for example the heat stability of an enzyme. The proteases in washing powder and the enzymes used in the polymerase chain reaction have been modified in this way, and it is an obvious approach to improve the usefulness of any enzyme, for example glucose isomerase, the enzyme used in the production of glucose syrup.

In plants, the first genes to be manipulated were the herbicide resistant genes. This is often put down to a 'plot' by the companies concerned to increase their sales of herbicides, and it is quite true that in discussions in which I was involved in the early 80's we, in a company, were aware of that opportunity. However the real reason they were selected was that the genes for herbicide resistance were single genes and therefore much easier to isolate and manipulate than the multi-gene complexes responsible for such important traits as salt tolerance and drought resistance. As you know a number of such herbicide resistant crops are now being grown.

However the first genetically modified plant product that came to the ACNFP for approval was the rot-resistant tomato from Zeneca and, a little later in this country, the 'FLAVR SAVR' tomato from the USA. Both these products worked in a similar way, though it was not in a way that could have been predicted, and arose from basic research. It was found that if a shortened second copy of a gene was present, in this case of the gene for the enzyme that breaks down the plant cell wall and so causes softening of the tomato, then the enzyme's action is inhibited, and the shelf life of the fruit extended. Zeneca chose to bring a paste made from their modified tomato to the

market first, since the processing would have destroyed all the DNA, both the modified and the original DNA. This simplified the approval process for ACNFP, and also helped reassure customers, who were likely to be cautious about this new product. Indeed, Zeneca took a great deal of care to explain the advantages of their new product, working closely with two major supermarket chains in giving a full explanation of what had been changed and why, and crucially, offering customers choice between this new product and the conventional one. The product sold well, and the marketing strategy had clearly been a success.

But why did the company take so much care? Because we had learned that such new products from genetic modification have to be introduced with great care. We used to think, we experts, that all we had to do was to decide whether a novel food or process was safe or not and a grateful public would accept what we said. We should have known better! Food irradiation, a process I, and many others, believe to be perfectly safe, is unusable because of fears connected with the word 'irradiation', going back to the atomic bomb and fed by concerns about nuclear-power stations. That should have made us think again. We had not grasped at that time the importance of consumer perception or understood the very different way the consumer sees risk. We learnt our lesson the hard way; by getting something wrong.

The importance of Consumer Perception

Early in the life of the Committee, in late 1988, we were asked to approve the use of a genetically modified baker's yeast, which had been developed by Gist-Brocades, by introducing two genes from a similar, but not identical yeast. This seemed to us a good case with which to start. After all, the genetic change could have been brought about by the naturally occurring yeast mating process. We could not see any problem, and said so, and in early 1990, a brief Press Release appeared which announced that 'the product may be used safely'.

The press reactions varied widely:

'Genetic yeast passed for use' in the Times,
'Man-made yeast raises temperature' in the Independent,
'Mutant yeast is half baked way to slice up nature' in Today,
and 'Are the boffins taking the rise out of bread?' in the Star.

While the Consumers' Association said:

'We think all genetically altered foods should be labelled'.

The general reaction was negative, and the product has never been used.

We dealt with this by gathering together, for a weekend conference, representatives of all the groups who might be able to help us avoid this problem in future. This included scientists, social scientists (especially to help us over risk assessment), civil servants, a philosopher, a churchman and representatives from the alternative groups. As a result,

we made a number of recommendations to Ministers, which were accepted, and we changed our procedure substantially. A consumer representative and an ethical advisor were added to the Committee. We also took a number of steps to open up the process, and make it more transparent. For some years now, we have produced an Annual Report and held an annual Press Conference. Press Releases are produced before and after each meeting of the ACNFP, as well as after Ministerial approval of each product or process. I see and sometimes reword the Press Releases; and also make a point of being available to reporters for both newspapers and television, for example over the brewer's yeast and, more recently, the herbicide-resistant soya and the insect-resistant maize. These changes have been in place for some years now, and have been the basis of all our subsequent decisions.

Then about five years ago, we were asked whether there were conditions in which meat from genetically modified sheep could enter the food chain. These sheep carried the human gene for Factor IX, a protein involved in blood clotting and needed for the treatment of haemophiliacs. The gene was introduced by injection into the fertilised egg before reimplantation and rearing. The introduced gene is present in all the cells of the animal, but is not active in all of them. And in this particular case, the clotting factor is released only into the animal's milk, from which it is readily purified. The process is, however, not very efficient. In many cases, the injected gene does not integrate and is degraded. In other cases, the gene is present, but not in a form in which it can work. So a large number of animals, often over a 100, are reared to obtain one animal which produces Factor IX in high yield. We were asked about the animals which contained no gene, and therefore were absolutely normal, and also about the animals which contained an inactive gene or only part of a gene. Could they be eaten? We could not think of any reason why animals without any foreign DNA should not be eaten. But were newspapers going to run the headline 'Failures from genetic engineering in your supermarket' if we said yes? What about the animals containing an inactive human gene? Was this just a stretch of DNA like any other? Or was it special, because it came from a human being? Would eating sheep meat containing a single human gene even be regarded as cannibalism by some? Would Muslims or Jews be concerned about pork genes in lamb, and vegetarians about animal genes in plants? We did not know, but decided that it was probably a wider issue than one of pure technical safety, and suggested to the Minister that there should be wider consultation. The Minister agreed, and a small group, which was chaired by the Revd. John Polkinghorne and of which I was a member, consulted widely, receiving submissions from a wide variety of groups, and also talking to a number of them.

We found that the Christians were, as you might expect, divided. Some had no objections, but many had an uneasy concern, which they found difficult to articulate, a feeling shared by many non-Christians too, which has been termed the 'yuk' factor. The Jewish reaction was more straightforward; for after all they have been dealing with subtle issues about food for many centuries. 'If it looks like a sheep, then it's a sheep' was their comment. Muslims and Hindus were much more opposed, as were the animal welfare groups and also the vegetarians. None of the groups were moved when we pointed out that there was effectively no chance of their eating the original human gene,

for it was hugely diluted in the processes of genetic manipulation, and the gene inserted into the sheep was more correctly called a 'copy-gene'. They were even concerned if the gene was completely synthetic. They were also concerned by the 'slippery slope' argument. These sheep had only one human gene in 100,000 sheep genes. But what if it was 50:50? They were worried too, about labelling, and wanted consumers to have choice. There was obviously quite widespread unease, and we made a series of recommendations to the Minister that put such restrictions on food use that in practise will mean that even the animals with no foreign genes will not enter the food chain.

The Importance of Co-decision

We have learnt, in the ACNFP, that scientific and consumer issues should be settled simultaneously, side by side, not consecutively as we used to do. The previous approach: 'First sort out the science, and then look at the consumer issues' simply does not work. A lesson we learnt first over the baker's yeast, and then over the transgenic sheep, where we realised, right at the beginning, that the question was not going to be resolved by science alone. So we asked a series of scientific questions - about chromosome fragmentation, mosaicism and the lower limits of detection of gene fragments - that we would not have asked but for consumer concerns.

So the climate for regulation is changing, and I believe that there are two pressures at work here, changing the way we will have to work in introducing new products. The first pressure is a growing ambivalence to new technology, and we must acknowledge that new technology has not always been for our long-term good. The deep ambivalence to new roads, the suspicion with which fluoridation of drinking water is treated, the caution over food irradiation, and above all, our recent experience with BSE has told us that, whatever the rights and wrongs of governmental policies, consumer perception is the real determinant. You cannot, as Margaret Thatcher said, 'buck the market', or the consumer.

The second pressure springs from the way the widespread availability of information, whether through education or the media, has changed many lives. Western societies are now increasingly made up of educated people who prefer to choose for themselves. Indeed education is now available world-wide, with high levels of skills being possessed by millions of people. An unprecedented amount of information is also available, for example through the increasing use of the inter-net. Many people see access to information as their right, and hierarchies, whether in companies or Governments, accustomed in the past to operate by managing the information flow, today find it hard to justify their position. Elites everywhere have to justify their positions; for they are no longer automatically accepted as the decision makers. Strangely, Universities, often seen as backward, have pioneered here. I had to assume, that in my job as Vice-Chancellor, everyone had access to all the information I had; and what I had to show in order for my proposals to be accepted was that they were the best choice, given our circumstances and priorities. So ACNFP, which has perhaps been the ground-breaker in changing the regulatory process, is now debating more change, and specifically, when and under what conditions could decisions be taken in public. We not only have to be as fair as we can, we have to be seen to be fair.

Herbicide Resistant Soya

But to return to modified plants whose products enter the food chain, and specifically to the Monsanto herbicide resistant soya. The ACNFP had no concerns at all about the safety of this product, and our sister committee, the Food Advisory Committee, did not require labelling, although it recommended the provision of information on a voluntary basis by the retailer; the practise followed in the case of the successful launch of the paste from genetically modified tomatoes earlier in the year. However, with this product, as you may know, the retailers have not been able to offer customers choice, because the genetically modified soya was not segregated the from 'normal' soya at the source. Even if commodity crops could be harvested separately, there remain very substantial practical considerations of maintaining separation throughout all of the subsequent stages of primary and secondary processing, food manufacture and distribution. This would require either separate batch operations or duplicate plant and equipment at each and every one of these stages. Retailers have responded to this problem by providing, and publishing (by IGD) a document entitled 'Communication and Labelling Guidelines for Genetically Modified Foods' as a contribution to an open and consistent approach to communication about the use of genetic modification in the food industry, and (by FDF) of a range of useful 'foodfuture' booklets and fact sheets. Consumers want to make their own, informed decisions, and food processors and retailers may have to respond by more extensive labelling. Meantime, according to The Times of March 25th, the IGD is working on an agreement with American farmers' organisations and distributors to ensure that genetically modified soya coming to Britain is separately packaged and labelled.

Antibiotic Resistance Genes

Similar but not identical issues surfaced when we came to look at antibiotic resistance genes in transformed plants. Specifically, we were concerned as to whether such genes were at all likely to be transferred to gut bacteria, and if so, did it matter? We recommended approval of the FLAVR SAVR tomato, despite it containing an antibiotic resistance gene, because the gene was controlled by a plant promoter, and therefore could not work in gut bacteria, and because the antibiotic in question, kanamycin, was not of great clinical significance. In contrast, we came to a different conclusion when we considered a modified maize from Ciba-Geigy, which was resistant to the corn-borer, a pest that leads to the loss of 5% of the world's maize crop. The Ciba-Geigy maize was turned back because of a number of reservations, the presence of a bacterial promoter in front of the penicillinase gene, the high copy number plasmid that had been used, and the very active penicillinase that might be produced, active against some clinically important antibiotics. So a variety of scientific skills, including clinical knowledge, were needed to deal with an issue that was driven by social and environmental concerns. We decided that although the technical risk was small, the consequential risk could be very large. Our scientific objection, coupled with the concerns of a number of member states over labelling, precipitated a problem in the EU, which was finally resolved at a high level in Brussels, the Commission deciding

that the scenario we were concerned about was very unlikely, and did not provide a sufficient basis for a ban on this product entering the EU. However, several EU countries, including Austria, Luxembourg and France, have refused to accept the Brussels ruling, often by decisions at the highest level, in the face of consumer pressure, and the regulatory process is currently in some disarray.

The Loss of Consumer Confidence

Why is this? Why do consumers want to make their own decisions? Basically I think because they have lost a lot of confidence in what they hear from politicians and to a lesser extent, from regulators. And what are the reasons for this loss of consumer confidence? Let me suggest several. First, scientists, and the expert approval processes, are no longer trusted as they once were. The 'man in the white laboratory coat' no longer recommends washing powder; the consumer does. Some of this may be due to a general 'decline of deference', but there are other reasons: scientists have sometimes been too influenced by commercial or political pressures, or just by the current of the times. Second, I think the public is largely unaware of the development of careful scientific methods of assessing risk, such as the use of hazard analysis, to come much closer to an 'objective' evaluation of risk. But it is also true that we find great difficulty in explaining, and the public in understanding, what is meant by different degrees of risk. Our National Lottery, with its slogan of 'It could be you', does not help either , the message is clear: even what is very unlikely may happen. It's been pointed out that you are more likely to die while watching the National Lottery than win the jackpot, but that doesn't stop people buying tickets; someone has to win! So even if the risk from a new product is very low, maybe it will be me! Third, the public finds it difficult to know how seriously to take the points put by the many single,issue pressure groups. Fourth, risks are assessed differently according to the context. We will accept quite high risks when we are seriously ill, but will not tolerate much risk at all with food. Medicine is restoring natural function to an organism already threatened, but food is the 'staff of life', a basic good that must not be threatened.

One explanation for such conflicting views is that scientists and the public work from different value systems. Scientists and technologists see novel applications of new discoveries as logical and reasonable, and characterise all opposition as unreasonable. 'If only they understood what we are doing' they say, 'the public would agree with us.' So there is much emphasis on the what is called 'The Public Understanding of Science', which I am sure is helpful, but it does always assume the scientist's value system as its starting point. Scientists are used to an uncertain world, where knowledge is always flawed, can handle risk judgements more easily, and, I am afraid, are impatient of those who differ from them.

The public's reaction is quite different, and it can be described as:

- Outrage , 'how dare they do this to us?'
- Dread , the way we would regard a nuclear power station explosion. A scientist

might think that the risk is so unlikely that it is not worth troubling over, but the public might decide that such an event is unacceptable at any risk level.

- Stigma , the way the public regard food irradiation

So scientists are regarded as arrogant, distant and uncaring. That's not a good image for science or for scientists.

Ethical and Environmental Concerns

There is another concern expressed by the public; some think that scientists are playing God. The public asks 'how do you know you are not going to release a new plague?' Scientists reply that they see living systems as a unity, knowing that cells, from bacteria to man, work in much the same way. So of course it's all right to move genes around - all we have to do is to explain it clearly, and people will be reassured. We are not abusing our position as the most powerful species. We know what we are doing.

I think this is all too glib. There are, first of all, important technical issues to be talked about, particularly environmental issues. Will herbicide resistance spread to weeds, will antibiotic,resistance genes transfer from plants to man through gut bacteria? The environmental issues are being carefully regulated by a parallel committee to the one that I chair: The Advisory Committee on Release into the Environment (ACRE). It is being careful and cautious, insisting on a series of controlled trials; first in a contained greenhouse, then in a carefully isolated field plot, before finally going out to planting. The pollen dispersal and the adjacent flora are being monitored to see if there is any spread of the GM crop. So far we're all right, but the situation wants careful watching, and concerns have been expressed that the 'case by case' approach used by the Committee will not deal with the sum of a series of decisions about release. It is therefore good news that an industry-wide code on GM crop information has very recently been launched, which aims to ensure traceability and best practise in use by establishing a consistent approach to information transfer for UK-grown crops from initial stock to primary end product. Recently too, the Nuffield Council on Bioethics has announced that it plans shortly to undertake an enquiry into the concerns expressed about the genetic modification of plants and how those concerns might be met.

It should be remembered that there are some situations in which a biotechnological process can replace one that is environmentally more damaging. For example, a recent process to make the blue dye indigo by a three stage process involving fermentation, cell separation and product formulation to replace an eight stage chemical process that uses and produces highly toxic chemicals.

There have also been criticisms that widespread introduction of genetically modified crops will lead to a loss of biodiversity. I am less concerned about this; the issue has been with us ever since advanced agriculture developed, and has been eased if anything, by modern biotechnology. We can already store valuable genes, and valuable genomes, as sequences in the computer as well as in the deep,freeze.

But there are other issues. There is the natural/unnatural issue. Some think that it is unwise, even unethical, to disturb the natural world , and that genetic modification is unnatural because it crosses species barriers. Others believe that BSE resulted from the 'unnatural' feeding of an animal foodstuff to a herbivore; in their view, BSE is a sort of Divine Judgement for upsetting the natural order of things. Now personally, I do not accept that all that is natural is best; fungal infection of crops with production of the ergot alkaloids is certainly not for the good of those who eat the crops. And why the yoghurt that I eat for my lunch is better for containing 'natural' colouring defeats me! I personally do not think there is an issue here.

But to go back to the beginning: why were the people we consulted so resistant to the idea of eating a human gene? Even when it was totally synthetic? Partly, I think, because they do not know where to draw the line between one gene and a thousand. Is this the start of a slippery slope? Surely we must be able to draw a line somewhere? I believe that we have to try. We already do so in other cases, for example in the case of experiments on very early human embryos.

But I think there is another reason as well. I suspect that people think that there is something special about human genes. Is there a concern about what science is doing to our perception of humanness? People are loving, caring, choosing human beings, with deeply held beliefs and values, many of which are central to their view of what a human being is. They accept the centrality of our genes , but not that we are no more than a bunch of genes. So they think that there must be something special about human genes, which must not be treated merely as chemicals. Is this a reaction to reductionism? A rejection of the idea that we are nothing but a bunch of genes? The concern of the public is not lessened by the aggressive determinism of some current biologists, or the slant of some of the science,education initiatives. Calling man 'the third chimpanzee' does not help.

It is also a warning to all of us, that in stressing the underlying simplicity and the order of the complex world which modern molecular biology reveals, and in stressing the power and effectiveness of modern technology, we must also stress its limits. Scientists, I believe, must be less assertive, less arrogant than is currently sometimes the case. Scientists are too often driven by their love of new technology, are unaware of the dehumanising effect of their innate reductionism and so are regarded as arrogant, distant and uncaring.

What about the Future?

What lessons can we draw from this to guide us for the future? Let me suggest four criteria for the development of new products:

- it must be technically possible, and now almost anything is possible,

- it must offer the consumer an advantage, and not just the producer,

- the regulatory process must be rigorous, open and universal,

- the consumer must be offered choice, at least for some time

Given these, I believe that biotechnology will dominate advances in the food industry, provided that the consumer understands and accepts the need for and the safety of the new products and processes.

The Technology Foresight process had some very sensible things to say about the Food and Drink Industry. Their list of priorities was long and quite complex, and much of it concerned the likely future structure of the food industry. But they had this to say about Science and Technology:

- A major factor influencing the future market will be the interplay of diet and health , leading to a demand for new product ranges, new ingredients and new forms of food processing. These are sensitive issues with consumers,

- S&T priorities include enhanced understanding of the links between diet and health, exploiting biotechnology for agriculture and food products, better understanding of the impacts of food processing, the application of modelling techniques in the organisation of production and, finally and importantly, research into consumer choice,

while biotechnology emerged as a key enabling discipline in the Steering Group's overall conclusions.

So what is biotechnology likely to produce? The most straight forward developments will be a whole series of new and improved enzymes for food processing and for the modification of existing foods, for example modification of fats. The science is straightforward, and there seems to be little consumer concern.

Now let me make some suggestions, roughly in a time sequence, for plants, for both speciality and commodity crops:

- Continued development of rapid genetic typing methods to speed conventional plant breeding systems, leading to the identification of genes responsible for desirable traits, and their transfer to other species, for example between the cereals. These methods will also make possible the unequivocal fingerprinting of a plant variety to establish Plant Breeders' Rights.

- Continued development of genetic manipulations, along the lines of herbicide resistance, involving one or more genes, with the production of plants resistant to many herbicides, and a wide variety of pathogens, including viruses, bacteria and fungi, thus greatly reducing or eliminating the huge losses due to these agents.

- Continued development of novel fertility systems, leading to the production of new F1 hybrids, with increased yields.

- Continued development of fruits and vegetables with longer shelf lives and better shipping characteristics.

- Modification of fatty acid synthetic pathways to produce oils containing different, and more suitable fats and starches for either dietary or industrial use.

- Genetic modification of fruits and vegetables with the aim of improving flavour, texture and nutritional content. Conversely, elimination of genes for toxicants and allergens.

- Isolation and utilisation of more complex genetic systems such as those controlling salt tolerance, drought resistance and response to day length making possible the production of plants which can be grown in a much wider variety of habitats.

- Isolation of the genes that control development means that we can start to manipulate flower shape and colour for the horticultural industry. For example, antirrhinums can now be made to flower to the tip, and recently a gene has been identified that makes stressed grass stay green longer.

- Similar isolation of the genes that control the plant's response to day length means that it may be possible, by modifying these genes, to produce plants that come to maturity more quickly, and so push north, for example the northern limit for growth of rape in Canada, with a huge economic impact.

- Production of drugs and vaccines in plants.

Developments in animals, apart from those leading to the production of high value/low volume drugs from transgenic animals will be slower; public concerns are much more serious. But some predictions are possible:

- Development of rapid genetic typing techniques will revolutionise animal breeding, enabling the identification of the genes critical for elite stocks and their transfer to others, using cattle, pigs and horses or poultry.

- Similarly, the identification of genes for undesirable traits will accelerate our ability to remove them from breeding stock.

- Better understanding of infectious disease pathogens should lead to the ability to breed animals with increased disease resistance.

- Genes could be introduced to enable cows to produce milk that is much closer in its composition to human milk for feeding to babies.

- A similar approach could be used produce transgenic animals with, for example, less body fat. However it will, I think, be some time before such animals are acceptable for food.

- Artificial insemination and embryo transfer will soon involve sperm sorting and nuclear transfer.

Summary

So in summary, we have in biotechnology a technology of immense power and promise; a pervasive technique that will enable the whole of the food industry to continue its aim of offering a wide range of safe and nutritious foods. We have a strong science base in the UK, and an open and responsive regulatory procedure which I believe has adapted well to a changing climate. But there are a number of hazards ahead. The first is the major consolidation that has taken place in the agrichem business; there are now less than ten companies world wide, and between them they control all the seed companies and all the plant and food biotechnology companies. Many of them are based in North America or on the continent of Europe, and I don't need to tell you what you already know - that they will research and manufacture anywhere in the world. What will keep them in the UK? I suggest:

- An informed and enlightened Government with a strongly supportive trade and industry policy.

- A strong and adequately funded science base, which is managed efficiently and toughly.

- An efficient and open regulatory system.

- A public prepared to accept new technology after thoughtful appreciation.

We are doing pretty well in most of these areas, but not as well as the US, now surely our only serious competitor, for our partners in the EU seem at the moment to be in some disarray. But the US seems to be determined to dominate world trade in the first quarter of the next century, and we shall have to work hard to stay in the game. What we're good at, and better than the Americans, is pulling together, and that means everyone including the OST and the Research Councils, the DTI, the MAFF, the Research Associations like this one, the FDF, the IGD and very importantly the Consumer Organisations. We have to make the sum more than the parts; then we shall see biotechnology really doing something for the Food Industry.