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RSC and IChemE joint response to the review of future directions in BBSRC-funded research relating to environmental change.

The RSC and IChemE welcome the opportunity to comment on the future priorities for BBSRC-funded research relating to environmental change (including climate change).

Learned organisations such as the RSC and IChemE will have a key role to play in the identification of gaps and opportunities for future research.

The RSC is the UK Professional Body for chemical scientists and an international Learned Society for advancing the chemical sciences. Supported by a network of over 44,000 members worldwide and an internationally acclaimed publishing business, our activities span education and training, conferences and science policy, and the promotion of the chemical sciences to the public.

IChemE is the hub for 27,000 chemical, biochemical and process engineering professionals worldwide. We are the heart of the process community, promoting competence and a commitment to sustainable development, advancing the discipline for the benefit of society and supporting the professional development of members
If you would like further information or need anything in this document clarified, please do not hesitate to contact me.

Yours Sincerely,
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Q1. In your view, what are the most important objectives for BBSRC-funded research in relation to environmental change over the next 10-20 years?

The RSC and the IChemE list the most important research objectives for BBSRC funded research in relation to the scope of the review.

<u>a. The science underpinning sustainable agriculture and aquaculture, covering soil biology, farming systems, land use and management.</u>

Farmers would benefit from better analytical and planning tools, enabling them to achieve higher yields and work more effectively and reliably with resources.

Objectives:

- Development of rapid *in situ* biosensor systems that can monitor crop ripening, crop diseases and water availability to pinpoint nutrient deficiencies and improve the quality and yield of crops.
- Analysis of climate change parameters, e.g. greenhouse gases and seawater salinity, generates input for predictive models, which can identify changing conditions for agronomy providing valuable data for the planting of new crops and management of aquaculture.
- Development of more efficient processes allowing the reuse of treated effluents and greywater, and the desalination of seawater for irrigation.
- Improved irrigation technology to increase precision, reduce losses, and reduce microbial contamination from soil-splash.
- Development of more efficient crop drying technologies which do not contaminate raw materials, especially in tropical countries.
- Improvement in the understanding of carbon, nitrogen and sulfur cycling to help optimise carbon sequestration and benefit plant nutrition.
- Development of fertiliser formulations with improved retention of nitrogen in soil.
- Optimisation of farming practices by understanding the biochemistry of soil ecosystems, for example the chemistry of nitrous oxide emissions from soil.
- Improved understanding of methane oxidation by bacteria (methanotrophs) in soil to help in the development of methane fixing technologies.
- In aquaculture, improvement of reproductive success, shelf-life of the finished product; development of favourable behavioural traits and built-in osmoregulation.
- Modelling of the effects of sludge’s and materials applied to land, including run off into surface water and percolation into ground water.

b. Adaptation to agricultural systems, including crop and livestock production; pests and pathogens of plants and animals, and farm animal health and welfare.

A rapidly expanding world population, increasing climatic volatility and limited land and water availability requires a significant increase in agricultural productivity.

Changes in weather patterns mean that traditional crops might not be best suited in order to satisfy the growing demand in food. For example, high downpours can cause crops to rot prematurely, having a significant effect on the crop yield and consequently food security. Selective breeding and changes in the type of crops that are grown under changed climate conditions need to be considered.

In addition agriculture is facing new and resistant strains of pests. For example, as a consequence of higher temperatures and increased precipitation humidity levels may rise, leading to ideal growth conditions for fungi, insects and weeds. Pests that are common in the Mediterranean region may become more common in the UK. This has significant implications for health and agriculture, because of the diseases the insects can carry e.g. malaria, and blue tongue disease.

The chemical sciences will be at the forefront in developing novel pest control measures and improving the resistance of plants to fungal, bacterial and viral diseases. Early warning systems and better monitoring techniques need to be developed in order to combat invasive species most effectively.

Crop production objectives:

- Use of modern biotechnology (including genetic modification) for the development of plants that:
  - withstand the effects of climate change (such as increased drought, and salt resistance);
  - have improved nitrogen-fixing characteristics;
  - enhance nutrition (by production of vitamins, omega-3 oils etc);
  - use fertilisers more efficiently;
  - resist disease and pests; and
  - survive on alternative nutrients.
- Improved understanding of the mechanisms involved in toxin production in crops and other plants.
- Understanding and exploiting biochemical plant signals for the development of new crop defence technologies.

Pest and Pathogen objectives:

- Development of natural pesticides using pheromones, semiochemicals and allelochemicals.
- New high-potency, more targeted agrochemicals with specific biocidal activity, which will help to protect biodiversity.

Livestock production objectives:

- Genetic engineering and modern breeding techniques of animals that:
  - will help to improve disease resistance;
  - reduce green house gas emissions;

- improve nutritional content and flavour of meat and improve feed conversion efficiency;
- pursuit of groundbreaking developments such as the EnviropigTM;
- engineering animal feed to improve performance and health;
- reduce feed costs; and
- produce more affordable protein.

Farm animal health and welfare objectives:

- Development of new vaccines and veterinary medicines to treat the diseases of livestock, which is crucial for sustainability. Development of new hormones for veterinary medicines.
- Development of novel ways of collecting samples from animals to replace blood-samples that will improve the quality of management and animal welfare, e.g. monitoring saliva to detect animals on heat.
- Development of new vaccines and veterinary medicines to treat the diseases of livestock and farmed fish, which is crucial for sustainability.

Animal and aquaculture feed objectives:

- Application of enzymatic and chemical modifications of lignified animal feed to improve access to celluloses and increase nutritional value.
- Better nutritional analysis of human food, livestock feed and fish feed, to understand the life-stage nutritional requirements of humans, livestock and fish.
- In aquaculture, development of a high-yielding omega-3 soya bean to replace industrial fish feed and reduce industrial fishing.

c. Food safety, in particular the microbial aspects of food-borne pathogens; also food spoilage

Food spoilage and deterioration is a major contributor to the massive problem of wasted food, and a key economic factor affecting global sustainability of the supply-chain.

Food spoilage objectives:

- To understand the factors affecting, and mechanisms involved in, the spoilage of food crops and other raw materials (as well as final foodstuff), with a view to implementing technologies and controls for their reduction.
- Development of bacteriophages and bacteriocins with antibacterial activity against foodborne pathogens and spoilage by microorganisms.

Food borne illness is a cause of ill health arising from a range of pathogenic microorganisms. It is estimated[1] that in England and Wales in 2000 the number of cases of foodborne illness was 1.34m; there were 20,800 hospitalisations and 480 deaths. In addition to zoonoses, physical, chemical and radiological contaminants can also pose risks to consumers.

Critical issues of food safety in plants, such as those associated with mycotoxin production in crops and foodstuff and contamination of susceptible crops eaten raw (such as salads) by pathogens, not only cause public illness but, by their nature, contribute to the overall problem of waste; and present an increasing challenge to control and manage.

Food safety objectives:

- Understanding the mechanisms involved in pathogen contamination of, and attachment to, susceptible crops such as salad crops, herbs and sprouted seeds, this includes the mechanisms of microbial adhesion to plant materials.
- Efficacy testing and food safety of new food additives, such as natural preservatives and antioxidants.
- Improved understanding of the genetic profile of pathogens, so that smarter and better-targeted methods of killing them or preventing their growth can be developed; research into new disinfectants which are environmentally benign and target more effectively the microorganisms involved in meat spoilage and the contamination of ready-to-eat food.
- Application of food metabolomics to the quality and safety of food – molecular profiling of food products to generate more comprehensive molecular descriptions of biological systems using analytical biochemistry techniques.

Improving intensive animal rearing practices with respect to microbial contamination of the animal and carcass, continues to be a major challenge. This issue will become more critical globally as meat production increases in developing countries.

Intensive livestock rearing objectives:

- Use of sensors and rapid diagnostics including on-line real-time identification of specific pathogen serotypes;
- Further development of antimicrobial supplements to feed and water;

[1] FSA (2007) Annual Report of the Chief Scientist 2006/7. Food Standards Agency, London. www.food.gov.uk/multimedia/pdfs/board/fsa071005a.pdf.

- Improved techniques for cleaning and disinfection; and
- Application of antimicrobial surfaces and equipment.

Harnessing of analytical chemistry to design rapid, real-time screening methods, microanalytical techniques and other advanced detection systems to screen for chemicals, toxins, veterinary medicines, growth hormones and microbial contamination of food products and their raw materials. To detect that they are not contaminated at source or during distribution, storage and processing, and that they contain required nutrients and are safe and fit for purpose, thereby avoiding their (re)processing, transportation or recall, and avoiding waste.

The use of intelligent packaging systems and technologies for the improved control of spoilage and food safety is a key area for further development and application.

Packaging objectives:

- Development of micro-sensors in food packaging to measure food quality, safety, ripeness and authenticity and to indicate when the 'best before' or 'use-by' date has been reached; for example, using biodegradable ink.
- Development of nanoscale biosensors in food, e.g. detection of food pathogens and toxins.

<u>d. Basic studies of the responses of plants, animals and microbes to changing climate and other environmental factors, in terrestrial and marine environments; also the interactions among species; and opportunities for novel biological solutions, especially for mitigation of climate change, but also to address other environmental changes such as bioremediation of contaminated land</u>

Detrimental environmental impact of agricultural production, e.g. soil degradation.

Objectives

- Development of field-based, rapid methods including dipsticks, immuno-labelling methods and lab-on-chip devices for environmental analysis to detect pollutants from primary production, such as pesticides or nitrates, that will help to pinpoint sources of diffuse pollution and allow methods for remediation to be put in place.
- Development of bioremediation technologies using microorganisms, and other living organisms, to degrade or detoxify environmental contaminants in soil, so reclaiming it for agricultural use.
- Development of chemicals for soil purification, e.g. sequestrants to complex toxic metals.
- Modelling of the effects of sludge's and materials applied to land, including run off into surface water and percolation into ground water.

The chemical sciences are critical in the treatment of water in both making it potable and also in removing contaminants from wastewater and industrial waste streams. With support the chemical sciences will aid the development of advanced treatment technologies such as membrane, ultraviolet and advanced oxidation processes. For example, it has been suggested that future developments could include smart pipes for water and wastewater distribution that monitor and treat water in situ. Additionally, the chemical sciences are important in the development of treatment technologies and standards for grey water and rainwater use.

Further research is required to understand the fate and environmental risk of emerging contaminants including pharmaceuticals and nanoparticles. With support, the chemical sciences will develop advanced monitoring technology, such as advanced sensors, to provide real-time information wirelessly on water quality and contaminants[2].

Objectives

- To predict the effect of climate change on global, national and regional water availability and quality, so as to inform adaptation and infrastructure planning.
- To develop portable technologies for analysing and treating arsenic and uranium contaminated ground water that are effective and appropriate for use by local populations.
- To develop advanced water treatment technologies that are highly effective and that significantly reduce energy demand.
- To develop, demonstrate, and deploy sensor networks that provide accurate real time measurements of the status of European water quality, so as to inform strategies for improving water quality across Europe.

[2] RSC Sustainable Water: Chemical Science priorities (2007) http://www.rsc.org/images/waterreport_tcm18-108403.pdf

- To understand and accurately predict the environmental fate of man-made chemicals, particularly emerging contaminants.
- To design chemicals and products that are highly effective in their use, and at end of life, are reusable and/or recyclable or degrade quickly in the environment.
- To widen the adoption of the principles of green chemistry, and the principles of integrated pollution prevention and control, to chemical manufacture, with an aim to reduce waste, energy use, and water use.
- To pursue the introduction of a universal statutory standard for sub-potable water in the UK so as to encourage grey water re-use.

Q2. What are the key barriers to meeting the above objectives, and how might they be overcome? In what topics might there be particular skills shortages?

The RSC and IChemE believe that the review panel should examine the ways in which BBSRC support multidisciplinary research. Publicly funded science is essential to the future prosperity of the UK. It is essential to fund multidisciplinary projects, as research grows more and more interdisciplinary. Responsive mode funding is crucial to the long term success of the UK's scientific research. The BBSRC will have to engage with funding bodies, government departments, including DEFRA and external stakeholders to ensure that the investigation of new and innovative science is appropriately funded.

It is particularly important that funding mechanisms are transparent and that the remit of the funding programmes is clear. There still remains confusion amongst scientists – especially at the interface between traditional disciplines – on where to best apply for funding. Funding opportunities need to be publicised widely and openly to improve recognition of their remit. The different funding bodies need to interact closely with each other to ensure that they are systematic in deciding which projects are funded by which funding body. The RSC and IChemE believe that it is important that the review panel enquires about how application processes for funding schemes of all funding bodies can be harmonised to reduce the administrative burden on researchers.

In addition there is a need for appropriate peers to review funding applications and better guidance for reviewers on how to assess multidisciplinary applications, so that research questions and appropriateness of method carry more weight than novelty of method.

In light of long-term challenges such as climate change and sustainability of food, funding opportunities should reflect the need for long-term and multidisciplinary projects. The review panel should enquire about how funding can be provided for expensive equipment and what mechanisms need to be in place for long-term measurements. The RSC and IChemE believe that commitment of funding agencies and grant holders need to remain continuous and reliable over a period of time to sustain research groups successfully and to produce reliable data.

Investment in technical skills is essential to provide the skilled work force that will implement key developments to combat challenges such as climate change.

The chemistry-biology interface is a burgeoning area of interdisciplinary research that plays a vital role in advancing understanding of fundamental principles underpinning biological systems and has high relevance to the challenges of climate change. It is therefore essential that appropriate training is provided at undergraduate and postgraduate levels so that the UK maintains a sufficient community of skilled researchers active in this field.
Interestingly, 42% of respondents surveyed for the RSC report[Error! Bookmark not defined.] identified that they did not feel that current undergraduates would be equipped to do research at the chemistry-biology interface. The RSC and the IChemE recommend that ffurther study is necessary to assess existing mechanisms for providing adequately trained interdisciplinary researchers.

Q4. Please comment on the potential priorities for future research (identified from the panel's initial discussions) set out in Annex 3. Please suggest alterations or additions to these priorities if you wish.

The RSC and IChemE support the preliminary list of proposed future priorities for BBSRC research, but recommend expanding proposed priority F 'Understanding and predicting the impact of environmental change on the marine environment', to include aquaculture and water management.

Marine Environment
Manmade emissions of carbon dioxide (CO_2) are causing the oceans to become more acidic[3].

Objectives:

- The extent of which calcifying organisms be affected at current CO_2 levels and at future projected levels.
- Research to identify the effects of ocean acidification on non-calcifying organisms.
- The effect of ocean acidification on the ratio of complexed to freely dissolved metals in the oceans, and its impact on aquatic organisms.
- Effect of ocean acidification on the availability (concentration, speciation etc.) of nutrients such as phosphates, silicates and ammonium ions.

Aquaculture
It has been shown that climate change will have a significant impact on world fish supplies[4]. For example, North Sea temperatures have increased by 1 ºC over the past 25 years, affecting the zooplankton that sandeels feed on, and this has played a contributory role in their decline. Climate change has altered, and continues to alter, the abundance and distribution of fish stock in EU waters, and DEFRA, working within the framework of the Common Fisheries Policy, has outlined its vision to address this and other fisheries issues[5,6].

Most wild fisheries are at or near their maximum sustainable exploitation levels[7]. Aquaculture presents an alternative to supply the future short fall in seafood. The growth of aquaculture over the next two decades will involve intensification, improvements in productivity through

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[3] RSC submission to the House of Commons Science and Technology Committee consultation: 'Investigating the Oceans http://www.rsc.org/images/RSC%20comments%20on%20Investigating%20the%20Oceans_tcm18-77427.pdf

[4] Allison, E.H. *et al.* (2005), Effects of climate change on the sustainability of capture and enhancement fisheries important to the poor: analysis of the vulnerability and adaptability of fisherfolk living in poverty. Department for International Development, London. www.dfid.gov.uk/pubs/files/summary-climatechangefisheries.pdf.

[5] Defra (2007) Fisheries 2027 – a Long-Term Vision for Sustainable Fisheries. Department of Environment, Food and Rural Affairs, London. See www.defra.gov.uk/marine/pdf/fisheries2027vision.pdf.

[6] Defra (2007) Delivering Fisheries 2027 – Towards an Implementation Plan. Department of Environment, Food and Rural Affairs, London. www.defra.gov.uk/marine/pdf/fisheries2027draftplan.pdf.

[7] Barange, M. (2005) Science for Sustainable Marine Bioresources. Plymouth Marine Laboratory, Plymouth. www.nerc.ac.uk/research/programmes/marinebioresources/documents/scoping_study_appendix.pdf.

breeding programs, modifications of the cultivated organism and feed research to reduce the dependence on fish oil and meal.

Water Management
One of the major climate change effects is likely to be in changes in precipitation levels, frequencies and duration. This will cause different flow patterns in water courses. These changes are critical for the management of water resource systems[8,9].

For example, flash summer flooding, relating to high intensity rainfall and surface runoff, will cause increased erosion and transfer of soluble and sediment bound pollutants to water bodies. Floods mobilise sediment and its entrained heavy metals and other pollutants as well as flush pesticides, parasites and nutrients from farmland into the watercourses.

Objectives:

- Understand the behaviour of contaminants such as pharmaceuticals, veterinary medicines, personal care products and nano-materials.
- Understand the behaviour and effects of transformation products including biochemical transformations. Information about the mechanisms and properties (e.g. persistence, mobility and toxicity) of transformation products is critical to fully understand the behaviour of contaminants in the environment.
- How future weather patterns will affect contaminant fate and transport is also not known. Temperature and precipitation changes due to global warming may affect the input of chemicals into the environment and their fate and transport in aquatic systems. There is a need to identify the potential impact of climate change on contaminant fate and behaviour.

[8] http://www.rsc.org/ScienceAndTechnology/Policy/Documents/water.asp
[9] http://www.rsc.org/ScienceAndTechnology/Policy/Seminars/FoodSecurity.asp

Q5. To what extent, and by what means, should BBSRC-funded research on environmental change be done in collaboration with industry?

The major growth of Chinese and Indian economies has encouraged the UK Government and Treasury to make the most of our 'knowledge' and move towards an innovation economy.

Universities need to create knowledge through research and subsequently disseminate it through publication, teaching, and knowledge transfer to both industry and society, for both the public good and the private profit.

In assessing the extent to which BBSRC-funded research on environment change should be done in collaboration with industry, it is important to question the desired outcomes: world class research, innovation, enterprise or wealth creation.

The RSC and IChemE recommend transparency in the process of engagement with a wide range of external stakeholders to ensure that the science carried out and sponsored by the BBSRC is relevant to current scientific technologies and future areas of importance.

Q6. Should BBSRC focus on science addressing primarily UK-related problems of environmental change, or take a more international perspective and look to the European or worldwide context?

Climate change is a global issue, however it is generally accepted that the effects of climate change will result in different environmental changes in different regions. For example, global temperatures have risen over the past decade and further temperature rise is predicted due to climate change. Depending on the scenario chosen to model UK temperatures, the average rise in temperature has been predicted to be between 1 °C and 5 °C by 2080. However, the local temperature rise is likely to be higher in the southeast than in the northwest. Warming is likely to be stronger in the summer and autumn than in the winter and spring. Heat waves are predicted to become more frequent and more severe[10,11,12].

Similarly, in the UK winter precipitation is predicted to rise, depending on the scenario, between 5% and 30%. Summer precipitation is predicted to decrease, leaving parts of the UK drier and rainfall is modelled to decrease between 20% and 40%, with the south and east being most severely effected. There is likely to be little change in autumn and spring precipitation. By 2080 the UK will most likely experience greater instances of flooding and drought. Risk of flooding is expected to increase because the rainfall intensity is predicted to rise. It has been suggested that drought frequency and severity will increase in most UK regions by the 2080s, but particularly in the south and east of the UK. Changes in precipitation will have consequences for river flows, ground water levels and hence pose new challenges for water management, agriculture, health, waste management, construction and infrastructure and transport[10,11,12].

It is therefore sensible that BBSRC funded research should focus primarily on addressing UK related problems of environmental change.

[10] http://data.ukcip.org.uk/resources/publications/documents/14.pdf
[11] http://www.london.gov.uk/gla/publications/environment/londons_warming_tech_rpt_all.pdf
[12] http://www.metoffice.gov.uk/research/hadleycentre/pubs/brochures/2005/climate_greenhouse.pdf

Q8. In considering agricultural systems, what should be the balance between research primarily relevant to local, low-input production and large-scale intensive systems? How might the current debate on long-term issues of livestock production be considered? What about long-term food security vs. energy needs?

Intensive agricultural systems

It is estimated that globally there is only an additional 5% to 10% of land of sufficient quality that could be brought into agricultural production[13]. Governments must resist the desire to bring more land into production especially if it starts to encroach into marginal land, forestry and naturalised/wild areas as this poses a threat of increasing the carbon footprint and reducing biodiversity. Furthermore, the effect of changing land use can be enormous in terms of releasing bound carbon into the atmosphere particularly if it entails bringing forestry into agricultural production.

Alternatively increasing productivity through using the best acres currently under agricultural production not only retains the high carbon storage areas such forestry but also retains areas of high biodiversity. Although agricultural production does contribute to the carbon footprint, with animal production being the most significant, farming practices, such as conservation tillage, help to retain carbon in the soil. In addition, crops produced by biotechnology are already contributing to the reduction of greenhouse gases according to a detailed environmental impact of GM crops 10 years after their introduction[14].

Agrochemicals have played a significant role in the increased yield and without them there would be approximately a 40% loss in agricultural productivity[15]. In wheat, for example, a combination of new varieties and crop protection products has seen a steady increase in UK average yields per hectare over the last 20 years[16].

The development of new technologies will help to realise the full potential of the plant. Technology can be applied in terms of enhancing productive growth and minimising losses due to environmental damage, disease, insect attack and weed competition.

Without pesticides, nearly one third of the world's crops would be lost before harvest. Those that reach harvest would then be exposed to further risks during transportation and storage. Pesticides also help protect human health by destroying disease-carrying pests.

Conversely, organic agriculture which only allows natural inputs into agricultural production has grown substantially in the last ten years. However, according to the FAO, it does not appear to be a feasible alternative to conventional agriculture[17].

Livestock production

The contribution of livestock to climate change amounts to 18% of the global warming effect, and is made up of 9% of total carbon dioxide, 37% of total methane and 65% of total nitrous oxide[Error! Bookmark not defined.].

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13 2004: FAO Summary of Food and Agriculture Statistics

14 2006: Brookes G and Barfoot P. ISAAA Brief N°36. ISAAA: Ithaca, NY. http://www.isaaa.org/resources/publications/briefs/36/download/isaaa-brief-36-2006.pdf

15 1994 :Oerke, Dehne, Schonbeck, and Weber

16 DEFRA Statistics

17 FAO (2008) Fertiliser and the Future. UN Food and Agriculture Organisation, Rome. www.fao.org/AG/magazine/0306sp1.htm

Growing consumption of livestock products correlates with an increased demand for animal feed, and is one of the contributory factors in pushing up the price of cereals. The most significant increase has been for wheat, and the price index has averaged 74.5% above the average for 2006/2007[18].

In the absence of corrective action, the environmental impact of livestock production will worsen considerably. However, as discussed below there are options for mitigation.

Intensive farming is characterised by high input use, striving for maximum production to provide food sources for large populations. However it must be balanced against the potential for environmental damage and address animal welfare concerns.

Methane emissions from livestock can be reduced through improved nutrition and genetics. A number of technologies exist to reduce methane through enteric fermentation, either by increasing the digestibility of the feedstuff through novel feed additives or by altering the digestive process of the animal[19].

In addition bio-filtration methods provide a mechanism for trapping ammonia and methane from livestock waste, and mitigating direct and diffuse pollution from agriculture at the level of field, farm and catchment[20].

The production of biogas by anaerobic digestion provides an effective method for turning residues from livestock farming (such as dairy, beef and pig slurry, or poultry litter) into:

- Biogas (rich in methane) which can be used to generate heat and/or electricity;
- Fibre which can be used as a nutrient-rich soil conditioner; and
- Liquor which can be used as liquid fertiliser with a defined nutrient content.

Genetic modification holds significant promise in reducing the negative impact of livestock on the environment. For example, researchers at the University of Guelph in Canada have developed a new breed of pig, trademarked the Enviropig™ that can degrade indigestible phytate and absorb the resulting phosphorous[21]. This eliminates the need for pig farmers to supplement the diet with phosphate, and, as a consequence, the phosphorus content of manure is reduced by as much as 60% compared to the manure produced from non-transgenic pigs.

There is considerable scope for using GM and genomic techniques, such as marker-assisted breeding, to support the sustainability of livestock. Benefits might include disease resistance, reduced greenhouse gas emissions, fertility, drought tolerance, improved nutritional content of meat, improved efficiency of feed conversion and enhanced palatability of meat through improvements in flavour and texture.

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[18] FAO (2008) Crop Prospects and Food Situation, No. 1. UN Farming and Agriculture Organization, Washington, DC. ftp://ftp.fao.org/docrep/fao/010/ah881e/ah881e00.pdf

[19] Rowett Research Services (2008) Novel Methods to decrease Methane Production from Livestock Animals. Rowett Research Institute, Aberdeen. See www.rowett.co.uk/resources/RRSOD.pdf.

[20] Pollock, C. *et al.* (2005) The First Report of the Sustainable Farming and Food Research Priorities Group. Dept for Environment, Food and Rural Affairs, London. www.defra.gov.uk/science/documents/RPG/Papers/FinalRPGreport.pdf.

[21] Golovan, S.P. *et al.* (2001) Pigs expressing salivary phytase produce low phosphorus manure. *Nat. Biotechnol.* **19**, 741-745.

Food security versus fuel
In order to boost national biofuel production arable land may be switched from food production to grow energy crops which are optimised for biofuel production by traditional plant breeding techniques and through genetic modification. In this scenario it is important that the implications for food production, for biodiversity and from the environmental impact of agrochemical usage are considered.[22]

The relatively low conversion efficiency of sunlight into biomass means that large areas of arable land would be required to allow a significant amount of the existing fuel pool to be substituted with biofuels. However, through multifunctional land use and second generation biofuels, food production does not necessarily have to compete with fuel production. This is particularly important when the implications of increasing population and the effects of climate change are considered for food production globally. It is important not to over-estimate the potential to produce energy crops. Land is the major limiting resource and biofuels should be seen as only part of a renewable policy that involves use of wastes, wind, wave, solar and other renewables. There is also increasing concern about the need for water to enable these crops to grow.

[22] Food Security and Sustainability, RSC, 2008 http://www.rsc.org/images/Food_security_tcm18-109038.pdf

Q9. What other specific considerations should be taken into account – e.g., potential use of gene technologies to address problems of environmental change, or the possible impact (positive or negative) of research outcomes on animal welfare?

Public opinion can have a profound effect on acceptance and implementation of new technologies. For example, the attempt to introduce products derived from GM crops into Europe more than ten years ago, without consulting the public, caused a backlash from consumer groups which fuelled public fear and suspicion of GM products. This led to a moratorium on the import of GM products and the growth of GM crops in Europe, which has only been lifted for a very limited number of non-food crops. As a consequence, the agrochemical companies developing products in this area reduced their presence in Europe and concentrated research and development in other regions of the world, such as the US, China, India, Africa and Brazil. One third of the world's GM crops are grown in developing countries.

Opinion on the potential benefits of GM crops is strongly divided. Although trials of GM crops are underway in many EU countries, and one approved strain of pesticide-resistant GM maize for animal feed is being cultivated in several countries (notably Spain, France and the Czech Republic), many consumers claim that they will never buy or consume GM products. Greenpeace and Friends of the Earth argue that cultivation of GM crops decreases biodiversity and increases pesticide application rates. They claim that GM crops have done nothing to alleviate poverty and hunger in the world and that they do not benefit the consumer[23]. They believe that we can use other food production technologies to meet the needs of the growing world population. The challenge is to produce realistic and robust data on which predictive models can be built, since the impact on agrochemical usage in maintaining, or even increasing crop yields will be compromised.

To be successful in securing consumer confidence, a different approach to the introduction of new technologies to that taken with GM in the 1990s is required, most likely based on effectively communicating benefits to the consumer. One of the problems for companies promoting GM crops is that the consumer does not see the benefits, in contrast to the use of GM in the pharmaceutical industry, where benefits to the public are much more obvious.

European Member States are struggling to agree a policy on GM crops, with individual countries imposing their own bans on specific GM products. The UK Advisory Committee on Releases to the Environment (ACRE) points out that novel crops produced by traditional non-GM breeding methods do not require extensive risk assessments, and that the current approval system is focused on risks of new GM plants and ignores their benefits. It concludes that a more balanced regulatory approach is required dealing with all novel crops and agricultural practices and allowing the assessment of both risks and benefits[24].

There are a number of challenges in improving public awareness of science:

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[23]Friends of the Earth (2008) Who benefits from GM crops? The Rise in Pesticide Use. Friends of the Earth International Secretariat, Amsterdam. See www.foe.co.uk/resource/briefings/who_benefits.pdf.
[24]ACRE (2007) Managing the Footprint of Agriculture towards a Comparative Assessment of Risks and Benefits for Novel Agricultural Systems. Defra, London. See www.defra.gov.uk/environment/acre/fsewiderissues/pdf/acre-wi-final.pdf.

- Understanding science: There is a lack of understanding around the complexities of science and scientific method. This leads to uninformed conclusions and governments can have a tendency to respond to public demands. To address this, science needs a rich, rational and open debate about its potential impact within our lives and in the context of a sustainable planet.
- Everyday science: Science has the potential to transform our lives for the better. It is everywhere and in everything and yet people are not aware of this. We need to find ways for science to be seen as a positive agent for change, at the forefront of improving our daily lives in sustainable ways.
- Democratised science: Access to relevant scientific information is no longer the sole reserve of scientists. The internet has democratised knowledge and made it accessible to all. The chemical science community needs to actively engage with the opportunities this presents and understand the benefits, while monitoring the integrity of the information provided.
- Science communication: The scientific community bears some responsibility for the fact that, in a number of areas, poor science has been allowed to lead thinking. The energy and passion of the scientific community must be communicated to the public to enrich and inform debate.
- Inspiring science: In every sphere of scientific enquiry at every level of expertise, scientific education is our main motor for improved public understanding and acceptance. Every available avenue and medium must be exploited to broaden and deepen scientific education.
- Risk taking: Western society is risk adverse and becoming increasingly litigious. Yet innovation and investigating the unknown are at the heart of good science. There is necessarily a risk / benefit trade-off and it is essential that we convince the general public that, without this, scientific breakthroughs cannot happen.

The RSC and IChemE have concerns that hazard based approaches and the precautionary principle are being used in situations where risk based approaches are more appropriate.

The appeal of hazard based approaches is that they are easier to apply and administer, however such approaches may result in misdirection of effort to mitigate risk because they do not deal with the likelihood that particular hazards may be realised. It is only through 'risk based' approach that the lowest reasonably practicable level of acceptable risk can be achieved.

A 'hazard based' approach that provides a ranked list of hazards is also flawed because in reality most options possess a range of different hazards that will vary in magnitude from one option to another and often in opposite directions. For example, a highly flammable solvent may be less toxic than an alternative solvent of lower flammability. Thus although options can be readily ranked in terms of a specific hazard such as flammability, options cannot be ranked in terms of their overall hazard. The decision to choose one option over another should be on the basis of overall risk.

Comparative risk assessment should aim to optimise the choice of options for a particular situation, taking into account potential risks to health, wildlife and the environment and the benefits to society as a whole.