Nuffield Council on Bioethics: New approaches to biofuels

EVIDENCE SUBMITTED BY THE SOCIETY FOR GENERAL MICROBIOLOGY

Introduction

The Society for General Microbiology (SGM), founded in 1945, is an independent learned and professional scientific body dedicated to promoting modern microbial science. It has established itself as one of the two major societies in its field globally, with some 5,000 members in the UK and abroad. Further information about SGM is provided in Appendix 1.

General Questions

Q1: *What is your view on society moving towards greater use of biofuels?*

It is absolutely essential that we move towards a greater use of biofuels for a variety of reasons, including future fuel security, agronomical diversification, boosting rural economy, and safeguarding the environment. Biofuels, in conjunction with other renewable energy technologies, can play a vital role in reduction of fossil fuel-derived greenhouse gas emissions.

Q2: *What are the most important ethical challenges raised by the prospect of future generation biofuels?*

- Affordability.
- Changes in land use for feedstock generation.
- The possible use of GM-feedstocks.
- Localisation and building of new refineries.
- Transfer from a one-size fits all fuel economy to smaller, more localized solutions may fragment the market and result in reduced economies of scale.
- Potential monopolization of bio-resources or patents

Sugarcane–derived ethanol from Brazil is currently the most sustainable and perhaps the most ethical biofuel currently being produced, but emerging second-generation biofuels particularly from waste material may be regarded as the most ethically acceptable.

Biofuels currently have a bad press and so scientists and policy makers face major challenges in communicating benefits of biofuels to wider audiences, including environmental pressure groups. Open discussion of ethical issues should be encouraged.

Q3: *Do you regard yourself as well informed about biofuels? Where do you get your information from?*

The SGM is reasonably well informed regarding biofuels. Many SGM members are actively involved in research into advanced bioenergy, and are therefore opinion formers in the field. Professor Graeme Walker (who contributed to this response) acts as consultant for international companies involved in producing the next generation of biofuels.

Drivers, hopes and benefits

Q4: *Which factors are going to be the most important in driving the development of biofuels in the future? To what policy concerns should priority be given? What advantages not mentioned here could and should future biofuel production aim to deliver?*

Currently, the main drivers for biofuel development are legislative. On the open market, biofuels are not currently competitive with fossil fuels.

An important driver for future biofuel development is sourcing *sustainable* biomass that does not deleteriously impinge on food security and environmental biodiversity, especially in developing countries.

Residual biomass in the form of lignocellulosic material should be a primary focus of attention for policy makers.

Alternative drivers include the decarbonisation of the energy market, potential impacts on global greenhouse gas emissions and a global deconcentration of energy production (*i.e.* energy security at a national or regional level). In addition, future biofuel production processes should aim to employ skilled personnel made redundant from declining oil and petrochemical industries. The emerging biofuels sector also offer opportunities in education and training of scientists and technologists and may also act as a general stimulus for UK science.

Climate changes

Q5: *Which of the new approaches to biofuels will be most successful in generating GHG emission savings? How should these be encouraged? Are there any reasons why these new approaches should NOT be encouraged?*

Biofuels will not actually result in a net reduction of GHG emissions, but a re-cycling of the CO_2 that is currently in the atmosphere. The only way to reduce the increase in GHG emissions is to stop burning fossil fuels or develop CO_2 sequestration technologies to fix atmospheric CO_2 as a mineral, rather than as a biomass component. CO_2 sequestration and biofuels production can be encouraged either by taxes on C-pollution, or by positive trading of C-credits; *i.e* CO_2 must be given a market value. Currently, there is no real choice of an alternative to fossil fuels as a liquid transport fuel for the consumer, so C-pollution taxes on liquid transport fuel would potentially be viewed with suspicion and undermine the credibility of “green taxation”.

Current research indicates that most savings on GHG emissions are accrued from lignocellulose-derived bioethanol. Such technologies should certainly be encouraged. Looking further into the future, however, it is conceivable that the biofuel providing even better savings on such emissions is biohydrogen. Mechanical engineering technologies in manufacture of new fuel-efficient flexible fuel internal combustion engines also have important roles to play in GHG savings.

Energy security

Q6: *Which of the new approaches to biofuels will be most successful in improving energy security? How should these be encouraged? Are there any reasons why these new approaches should NOT be encouraged?*

Waste biomass to biofuel technologies should be encouraged, possibly through specific governmental tax incentives. Lowering usage of vehicular and aviation transport is a non-starter in terms of ensuring future energy security. Therefore, in addition to increasing the proportion of sustainable second-generation biofuels in petrol and diesel mixtures, new fuel-efficient and flexi-fuel internal combustion engines are essential. Some parts of the UK view energy security as meaning electricity security. However, by far the greatest GHG emissions emanate from liquid transportation fossil fuel combustion. The UK also urgently needs to lessen imports of foreign (often Brazilian) bioethanol to meet RTFO and EU Directive targets (and concomitantly reduce carbon foot-printing).

We should also move away from seeing biofuels through the prism of fossil-fuels. Coal and oil are complex mixes of hydrocarbons that can be used in a variety of industrial processes with relatively little waste. Conversely, biofuels are generally composed of relatively few, rather dilute components. We therefore need a paradigm-shift to view biofuels as integrating different technologies that will potentially have variable outcomes in diverse environments. Consequently, in this largely research-dominated phase, we should not close the door to any new technology or development, without a careful lifecycle (‘field-to-wheel’) analysis.

Economic Development

Q7: *Which of the new approaches to biofuels will be most successful in supporting economic development? How should these be encouraged?*

Are there any reasons why these new approaches should NOT be encouraged?

- Biofuels that most closely align with current infrastructures and knowledge (*e.g* microbial fermentation) and that can benefit from economies of scale would be immediately economically useful.
- Biofuels that make use of otherwise waste products, such as CO_2, heat from industry, waste urban water, agricultural waste (*e.g.* lignocellulosic ethanol or algal biodiesel) or municipal solid waste (e.g. tons of food waste generated daily from British supermarkets) will also be of economic benefit. However, a major threat to the large-scale production of advanced biofuels is the limited knowledge of scale-up possibilities.
- The most successful biofuel operations in the future will be truly "biorefineries" that convert biomass into a variety of value-added commodities, including biofuels. For example, the Brazilian example of converting sugarcane into bioethanol, fertilizer, animal feed, electricity (surpluses to grid), bioplastics* etc. represents an aspiring biorefinery concept.
- A consistent method of life-cycle analysis for fossil- and bio-fuels should be agreed. Is well-to-wheel or field-to-wheel sufficient?; should the energy expended in exploration and drilling for petroleum or for feedstock culture also be take into account?; what are the implications of refining, transport, distribution? This comparison will enable markets to make decisions on the optimal structure of the future biofuel industry
- Development of aviation biofuels should also be encouraged, for example, bioethanol for light aircraft and biobutanol and biodiesel for commercial aircraft.

*Coca-Cola (Japan) Co. will introduce PET (polyethylene terephthalate) bottles made using dehydrated Brazilian bioethanol in the spring of 2010. Other bioplastics are polyhydroxybutyrate via a bacterial fermentation of sugarcane molasses and polylactate from maize syrup (eg. Cargill, Nebraska).

Science, technology and research

Feedstock development and processing

Q8: *Of all the new approaches to biofuel feedstock development, pretreatment and processing (including any additional to those mentioned here), which is looking most promising for eventual commercial and sustainable use? Over what* *timescales might such developments be commercialised? Are there any risks associated with these developments?*

- First generation bioethanol is already under commercial production with established feedstock production/processing and refining methods; however, the production of ethanol from glucose is not globally sustainable as sugar represents energy that can be used as human or animal food.
- Lignocellulosic ethanol from indigestible plant waste is possible and a very promising technique that can be applied more globally. Some companies (notably many in the US, and a few in Europe) are already producing ethanol from lignocellulose, including hardwood chips, so some technologies are already here. Further research into appropriate enzymes and bio-catalysts is required to increase yields and the efficiency of lignocellulose digestion. Several low-energy lignocellulose pretreatment technologies are being developed and some hold promise for commercialization. For example, ultrasonic treatments combined with ozonolysis (or other oxidants) prior to enzymolysis may prove successful. Risks relate mainly to maintaining favourable energy balances and cost efficiencies. Target net energy balance ratios are 10:1 (or higher). Environmental risks can be minimized by pelletizing lignin residues for direct combustion in biofuel plants for energy self-sufficiency and surplus generation to the grid (as per bagasse in Brazil). Other residues may also be anaerobically digested to biogas.
- Microorganisms that generate long-chain hydrocarbons from sugars are currently under intensive research, but are not currently compatible with anaerobic digestion.
- In terms of novel feedstocks, marine biomass (e.g. seaweeds, macroalgae) hold great promise for bioethanol production and they may not require the same level of energy input during pretreatment. However, research into advanced liquid biofuels from algae is at a very preliminary stage and the timeframe for implementation could be measured in decades, rather than years. Other un-exploited marine residues include chitinous waste from shellfish processing and several novel chitinases are being researched.
- Finally, biodiesel from photosynthetic microalgal carbon dioxide reactors (and open-air solar ponds) make a lot of sense from a number of perspectives, especially if utilizing CO_2 from bioethanol plants in an integrated biorefinery.
- For bioenergy production, one of the simplest and most cost-effective solutions is biomass burning to generate electricity.

Advanced plant breeding strategies, genetic modification and synthetic biology

Q9: *Is the use of the following technologies to develop new approaches to biofuel production appropriate? Why?*

Advanced plant breeding strategies

Advanced plant breeding strategies may be especially useful in developing new traits in grasses to be cultivated specifically as energy crops (e.g. rye grass, SRC, and Miscanthus). This approach also avoids controversies surrounding GM techniques. However, depending on the crop and the traits that are desired, advanced plant breeding may still take some time to generate biofuel feedstock crops.

Genetic engineering

Genetic modification is a good solution for organisms that will be contained, *i.e.* the biocatalysts that transform feedstock to fuel in a closed bioreactor such as recombinant yeasts and bacteria. For example, some cellulolytic microbes can effectively be exploited in SSF (Simultaneous Saccharification & Fermentation) processes which lessen the financial burden in using expensive commercial enzymes.

Some molecular genetic research in plants to reduce lignin may be viewed as somewhat pointless if lignin can be pelletized and used for renewable energy. Also, lignin hydrolysis products can act as progenitors for useful chemical and pharmaceutical commodities. From a plant physiology perspective, low lignin does not make sense (if cultivated in windy environments). Plant genetic engineering strategies for developing drought-resistance traits in energy crops are very worthwhile from an environmental security perspective. Although GM technology will enable plants to be more rapidly and precisely tailored to the requirements of a feed-stock rather than a nutritional use, GMO culture in fields is currently not acceptable to the European public and will require a major shift in policy to implement.

Synthetic biology

Synthetic biology is at a very early stage of development. The development of GM biocatalysts is underway and the insertion of entire metabolic pathways into micro-organisms has been documented. Although we are a long way off in terms of wholly synthetic genomes expressing complete biofuel pathways in chassis “organisms,” biohydrogen from synthetic biology may emerge as practical reality in the future.

Intellectual property issues

Q10: *What are the most important intellectual property and access issues raised in new approaches to biofuels? What is the best way of governing these?*

Intellectual property issues are probably similar to those for any industrial application of biology. IP issues concerning recombinant microbes are very important and companies must be free to protect their considerable investment in R&D in this area. Differences in patent law between countries and the infringement of patents may require supra-national government and negotiation in the global biofuels arena.

Research and development (R&D)

Q11: *What are currently the main constraints to R&D in new approaches to biofuels?*

General constraints:

- Biofuels R&D is, by necessity, a multidisciplinary process. A major constraint is a lack of constructive, two-way communication between the research-base and the end-users (in this case industry) as to their respective requirements.
- There is a perception that applications-driven (rather that hypothesis-driven) research in Universities is not directly fundable by Research Councils.

Specific challenges:

The main scientific and technological challenges relate to efficient and energy-favourable bioconversion of lignocellulosic biomass to bioethanol. Current constraints are manifold, with microbiological (fermentation) problems at the forefront (e.g. inefficient cellulolysis, lignin and hemicellulose-derived inhibitors, simultaneous pentose and hexose fermentation etc.). We are a very long way off achieving the ~20% v/v ethanol yields using second-generation substrates that are now achievable with maize and sugarcane processes.

The same constraints do not pertain to biodiesel production and transesterification processes which are quite mature from an industrial perspective. Biogas (methane) generation via anaerobic digestion has been around for many years, but remains relatively unexploited.

Regarding another fuel alcohol, namely biobutanol, there remains several important constraints to these re-emerging processes, not least the low yields of fermentation butanol produced by solventogenic anaerobic *Clostridium* spp. Some novel approaches using recombinant yeasts to produce butanol hold great promise (as per approaches being developed by companies such as Gevo Inc, USA). It is important to note that butanol has considerable advantages over ethanol as a biofuel, not least regarding combustibility, transportability and miscibility with mineral diesel.

Q12: *Where should R&D for new approaches to biofuel be targeted, and who should decide about future biofuel R&D strategies?*

Research funding should be mainly targeted to Universities and development funding to industries. As justified in previous questions, R&D should be focused on efficient bioconversion of lignocellulosic biomass to bioethanol using novel pretreatments, hydrolyses and fermentation technologies. Aviation biofuel R&D should also be targeted. Small-scale biofuel production units should also be researched (e.g. the almost DIY-bioethanol kits available from companies such as E-Microfueler in the US).

It is difficult to pinpoint who should be deciding on future strategies, but research councils in the UK may not be particularly well advised in this context. In general, Governments in Europe are slowly switching on to developing biofuel strategies. The US is leading the way with enlightened policies. For example, the US biofuels industry was undoubtedly glad to hear President Barack Obama place a priority on renewable energy in his State of the Union address (28/1/10). To ensure the growth of US biofuels, regulators must approve E15 and other higher blends and extend the tax credit for all ethanol feedstocks.

Land use, environmental and food security and human rights

Land use

Q13: *Are new approaches to biofuels likely to raise problems related to land use? If yes, how? If not, how do new approaches avoid these issues?*

The large-scale cultivation of biofuel feedstock will inevitably lead to a change in land-use, with an increase in farmed landscapes (fields, forests, ponds, marine farms etc). There is a widespread misconception that the huge Brazilian bioethanol industry is leading to rainforest destruction. However, the vast majority of Brazilian cultivation of sugarcane (and the bioethanol distilleries) is located in Sao Paulo state, using degraded pasture land. There are therefore few problems related to land use for bioethanol in Brazil which is the world’s second largest producer.

Concerning second-generation bioethanol, there are huge opportunities to utilize woody wastes, forest products and energy grasses from vast areas of currently uncultivated/unexploited land.

Changing landscapes will inevitably lead to a change in habitat. However, controlled development could actually enrich habitat diversity in some regions of the world; for example a marine macroalgal “farm” may provide a protected nursery for marine animals.

Undoubtedly, there are land use problems associated with certain biofuels notably, cereals for bioethanol and palm oil for biodiesel. Governments can assist in alleviating such problems by ensuring sustainability of biofuel biomass (e.g. UK’s RTFO regulations).

A major issue regarding biofuel production is the competition for fresh water: the USA DoE estimates that 830l of fresh water is required to produce 2.7kg of corn, yielding 1l of first generation bioethanol and 5,900l of fresh water is required for 6kg of soy, yielding 1l of biodiesel. Fermentation and distillation are also intensive water-using industries. It is therefore possible that the main impediment to the developing biofuels industry is not land, but the availability of water for irrigation and processing.

Q14: *What differences are there between the developed world and developing countries with regards to the potentially problematic effects of future generation biofuel production on land use?*

Developed countries are mainly located in temperate zones, whereas developing countries are sub-tropical to tropical. Developed countries have largely transformed their landscapes and reduced native biodiversity, but developing countries are in the process of doing so. Land and water use, whether for crops to feed an increasing population, or for biofuel, has impacts on natural ecosystems and biodiversity.

The sustainable Brazilian bioethanol industry may be quite unique compared to other aspiring countries due to vast acreages available for biofuel crops in that country. Thousands of hectares in the mid-west of the US used for maize cultivation for bioethanol are similarly not replicated in many other developed and developing nations. The most contentious land use issues in developing countries relate to Indonesian and Malaysian palm oil cultivation for biodiesel, with the concomitant environmental and social problems caused by deforestation. Perhaps new international laws dictating that developed countries only import *sustainable* biofuels from developing countries would help alleviate such problems.

Q15: *Should iLUC be considered when evaluating the GHG emissions savings of new approaches to biofuels, and if so, how?*

Transfer from food production to biofuel feed-stock culture is a threat to food security and may impact greenhouse gas emissions. Consistent monitoring of the impact of biofuel feedstock culture should be undertaken to more accurately inform the cost/benefit aspect of biofuel production.

Environmental security

Q16: *What advantages and disadvantages for environmental security could new approaches to biofuels have? How could harms for environmental security be dealt with?*

The most significant advantage of biofuels is the decarbonisation of the energy sector and the concomitant reduction in GHG emission from fossil fuels. Other advantages include the globalization of energy sources and increase in recycling (for instance using waste lignocellulose from food-crop as a feedstock for bioethanol production or waste water from urban sewerage works for algal growth).

There are advantages related to use of “degraded” land for biofuel crop cultivation (as per Brazilian sugarcane example) that would otherwise lie uncultivated. New genetic engineering strategies, for example, in developing drought-resistant crops have distinct advantages for water savings. Some enlightened biofeineries utilize stillage/vinasse for valuable soil-improving fertilizers.

Threats to the environment include biodiversity loss from increased development of arable and marginal lands and increased water use. Biodiversity reduction is problematic for several biofuel crops such as vast acreages of mono-cultured maize in the US and palm cultivation on deforested land in Indonesia. Mitigation of these threats might include controlled land and resources use through a legislative framework.

Food security

Q17: *Are new approaches to biofuels likely to raise problems related to food security? If yes, how? If not, how do new approaches avoid these issues?*

New biofuel technologies exploiting whole-crop biomass, including lignocellulosic material, are likely to lessen (rather than increase) problems of food security since biofuel yields per ton of biomass (or per hectare plant) will be augmented. Further exploitation of non-food energy crops for biofuels will additionally help in this regard. For developed countries, there is currently a huge problem of food wastage, from both domestic and retail sources. Some biofuel companies have recognized these sources as potentially fermentable carbon sources, for bioethanol production. This should be recognized in any food security evaluations. The development of biofuel crops on marginal lands that are not used for food production, notably algae or forestry crops, may mitigate the threat that biofuels pose to a secure food supply.

Q18: *What differences are there between the developed world and developing countries with regards to the potentially problematic effects of future generation biofuel production on food security?*

The developed world is calorie rich in food, and can afford to divert some of these calories to fuel. The developing world is often calorie poor in food, and diversion of energy to biofuels might therefore have a disproportionately large impact on food supply in these regions. Both developed and developing countries will benefit from a food security perspective if lignocellulosic biomass and waste food material can be fully utilized in biofuel fermentations. Comments in response to Q 17 are also relevant to this question.

Rights of farmers and workers

Q19: *Are new approaches to biofuels likely to raise problems related to rights of farmers and workers? If yes, how? If not, how do new approaches avoid or benefit these issues?*

Rights of access to natural resources, including land and water, are likely to become more pressing issues if agriculture is also used for biofuels as well as food. However, new technologies and industries will likely provide a general boost to rural economies in terms of new jobs and income generation. Small scale, on-farm biofuel production units are feasible especially regarding biodiesel production (e.g. for farm vehicle, machinery use). Anaerobic digesters (for biogas) can also be successfully scaled-down. Even bioethanol units have been scaled down for individual consumers (eg. E-microfueler).

Q20: *What differences are there between the developed world and developing countries with regard to the effects of the production of future generation biofuels on the rights of farmers and workers?*

If localized biofuel production plants in developing countries can be profitably operated, this would provide job security and financial independence from larger biofuel companies (including multinational oil companies that are rapidly diversifying into biofuel production).

Investment, policy and governance

Q21: *Where do you think investment in new approaches to biofuels should be directed and where should it come from (public sector, private sector or public-private partnerships)?*

Investment for research and development should be directed to second-generation biofuels, notably lignocellulosic bioethanol processes. New investment in biofuels should be directed at specific problems, identified by scientists, governments, industry and the markets. Investment should come from all stakeholders including tax revenue and industry. A multidisciplinary approach is desirable, but the difficulties of managing such projects should not be underestimated.

Fundamental research activities (e.g. in molecular biology, microbiology, fermentation technology) should continue to receive prioritized funding from national research councils, EU Framework programmes etc. Individual University spin-off and entrepreneurial companies attract investment from venture capitalists. At the other scale, large multinational oil and petrochemical companies have invested heavily in biofuel R&D in recent years, and this is likely to increase in the future. [For example, BP Biofuels, Exxon, Shell, Petrobras, Du Pont etc].

In the aviation biofuels sector, there is a need to increase public and private funding for basic research. Some enlightened companies are at the forefront of aviation biofuel developments (eg. Virgin Biofuels).

Q22: *Which policy issues in relation to new approaches to biofuels would you like to bring to our attention?*

Policies that specifically promote second-generation bioethanol processes would be worthwhile and forward-thinking (because cereal starch-based processes are ultimately unsustainable). Regulation should always have biofuel biomass *sustainability* at the forefront. Lignocellulosic wastes generally meet such criteria and policies should specifically incentivise their exploitation.

The following points should also be taken into consideration:

- Biofuels are at best carbon-neutral, and will only impact global GHG emissions by reducing demand for fossil fuel.
- The development of more economical engines that can function on biofuel is essential.
- Novel tax regimes that give a cost to CO_2 pollution are required, but only when viable alternatives are available to consumers.
- Biofuel production should be incorporated into recycling streams.
- Water use is likely to become as large an issue as land use; water must therefore be apportioned in a fair manner.

Q23: *What would be the most effective policies a) to promote and incentivise; and b) to regulate the development of new approaches to biofuels?*

A: Promotion and incentivisation – Carbon credits should be introduced as well as incentives for recycling; *i.e.* ascribe a value to products that are currently considered as waste.

B: Regulation – Biofuels should produce more energy than they consume, from life-cycle analysis of the entire system of production.

Comments in response to Q22 are also pertinent to this question.

Q24: *Are there any other issues not mentioned in this consultation that we should consider in the ethical evaluation of new approaches to biofuels?*

There is little mention of science, technology, socioeconomics and bioethics of the following:

- food wastes (and municipal solid waste, MCW) as biofuel substrates
- marine biomass (macroalgae, chitin etc.)
- aviation biofuels
- biobutanol
- biohydrogen
- small-scale biofuel production units

Sources

This response was prepared from written evidence provided by Professor Graeme Walker from the University of Abertay Dundee and Dr John Love from the University of Exeter

Appendix 1

The Society for General Microbiology (SGM) was founded in 1944/1945 and is now the largest microbiological society in Europe. It has over 4500 individual members of whom 75% are resident in the UK. The remainder are located in more than 60 countries throughout the world. Almost all full members are qualified to doctoral or higher level; there are 1000 postgraduate student members. More than 700 schools and a number of companies are corporate members.

The Society provides a common meeting ground for scientists working in academic centres and in a number of fields with applications in microbiology (medicine, dentistry, veterinary medicine, pharmaceuticals, numerous industries, agriculture, food and beverages, the environment and education). The majority of Society members are employees of universities, research institutes, health services, government agencies and small to multinational companies.

The science of microbiology covers a great diversity of life forms: disease-related molecular structures such as prions and viruses, archaea, bacteria, fungi, protozoa and algae. Microbes are of crucial importance in a number of processes affecting all life on Earth: the cause and control of disease, fertility of soils and aquatic environments, fermentation, biodegradation of waste materials and dead biomass, bioprocessing steps in drug and antibiotic production, and molecular biotechnology.

The Society's objective is to advance the art and science of microbiology. It does this by:

- Organizing regular scientific meetings at centres throughout the UK and abroad, where microbiologists meet to hear and discuss the latest research findings. The largest meetings last 4 days and involve up to 1400 participants.

- Publishing four major international learned journals: *Microbiology, Journal of General Virology, Journal of Medical Microbiology* and *International Journal of Systematic and Evolutionary Microbiology*. The journals are available on-line through HighWire Press (http://www.sgmjournals.org).

- Representing the science and profession of microbiology to government and the media. The Society is represented on a number of biological and biomedical committees and organizations, in the UK and internationally, thereby exerting influence on science policy and education, regulatory affairs and international collaboration.

- Promoting microbiology as a career for young people, by increasing awareness of microbiology in schools and aiding the development of teaching resources. The Society also provides grants for young scientists to attend scientific meetings and training courses.

- Keeping members informed of current developments in professional and scientific matters in microbiology, through publication of the magazine *Microbiology Today* and other means.

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Marlborough House
Basingstoke Road
Spencers Wood
Reading RG7 1AG, UK

Telephone: +44 (0) 118-988 1800
Fax: +44 (0) 118-988 5656
Web: http://www.sgm.ac.uk

Contact: Dr R S S Fraser, Chief Executive, e-mail: r.fraser@sgm.ac.uk