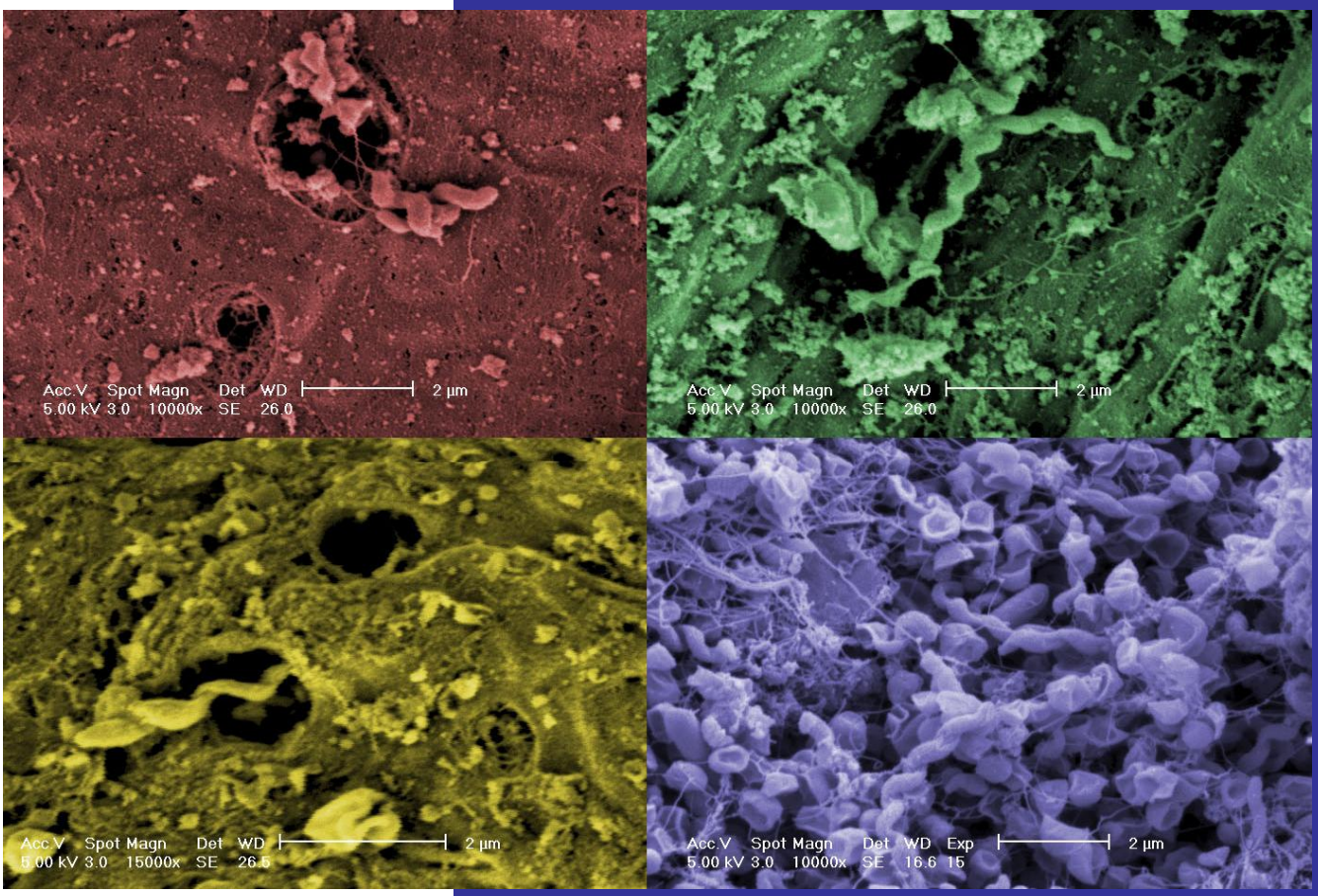
UK Research and Innovation Strategy for *Campylobacter* – in the food chain

2010-2015



A number of partners involved in this strategy are also members of the Global Food Security programme.

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Cover Illustration, photos provided by Dr Andrew Grant and Professor Duncan Maskell

Foreword

I welcome this strategy as an exemplar of how funders can work together in a co-ordinated approach to tackle the complex research issues needed to address the significant issue of *Campylobacter* in the food chain. This is a good model of the principles outlined in the UK Cross-Government Food Research and Innovation Strategy launched earlier this year.
Professor Sir John Beddington, Government Chief Scientific Adviser

Campylobacter is the major cause of foodborne illness in the UK, causing sickness in over 300,000 people each year. For some this is a particularly nasty infection – around 15, 000 people are admitted to hospital for treatment and around 80 people die every year in the UK. The Agency is determined to reduce the public health burden of this preventable illness and is working with different sectors of the food industry to control and reduce levels of *Campylobacter* in chicken. Whilst there are control measures that can be taken now, there remain gaps in our knowledge so I am delighted that the FSA, Defra and BBSRC have been able to come together with other partners to develop this Joint Research Strategy and also to share resources to develop a high quality evidence base in a more coherent way. I look forward to us jointly sourcing the high quality science needed to have a real impact on this major public health problem.
Dr Andrew Wadge, FSA Chief Scientist

Campylobacter is a highly complex organism and we will only be able to understand it more fully and to overcome the threat it poses by deploying world-class research across microbiology, immunology and molecular biology. To ensure this new strategy is a success we need to bring together not only bioscientists, mathematical modellers, vets and social scientists but also relevant policy and industrial representatives. Addressing the *Campylobacter* challenge involves two of the three BBSRC strategic priorities of food security and basic bioscience underpinning health, in addition to exploiting systems approaches and new research tools. Working with other funders and industry will ensure the translation of excellent science to deliver important impacts that affect every consumer.
Professor Douglas Kell, BBSRC CEO

Campylobacter infections cause more food-borne illness that any other organism in the UK. The complex ecology and biology of the organism mean that the development of effective risk reduction strategies are a major challenge for Government, livestock producers, processors and retailers. It has been clear for several years that no one intervention will provide even a partial solution. A multidisciplinary approach which seeks to intervene at a variety of points in the food chain is required and I am delighted that this document sets out such an approach. Many producers, processors and retailers were involved in its development and I look forward to their continuing contributions during the life of the strategy.
Alick Simmons, Deputy Chief Veterinary Officer, Defra

Executive summary

The purpose of this strategy is both to articulate the importance for the funders to tackle *Campylobacter* research in a coordinated and coherent way, and to provide researchers and the industry with a clear list of research priorities in order to focus and stimulate their efforts around common structured goals. The delivery of the research will be through a variety of funding routes currently used by the funders with the possibility of additional activities as appropriate.

Food security is an increasing priority for the UK Government and food safety is a key component of this. *Campylobacter* is the most common cause of food poisoning in the UK and is responsible for an estimated 321,000 estimated cases in England and Wales in 2008[1], with over 15,000 hospitalisations and 76 deaths. *Campylobacter* accounts for a third of the cost of food-borne illness in England and Wales, estimated at £583 million in 2008. It is found mainly in poultry but also in red meat, unpasteurised milk and untreated water. Although it does not normally grow in or on food, it can transfer easily. Illness can arise from only a few bacteria in undercooked chicken, or in ready-to-eat foods that have been cross-contaminated from raw chicken. *Campylobacter* infections do not usually cause vomiting, but diarrhoea can be severe and bloody, with additional abdominal cramps.

The three major public UK funders of *Campylobacter* research currently spend more than £4 million per year to address basic, applied and policy related research. Each has its own research priorities, but all pursue high-quality research that provides sound scientific information on which to base government policies and advice on industry and consumer practices. This strategy provides a new focus in developing joint priorities between the main UK public funders, in consultation with the industry, to help deliver coherent and coordinated research.

The overarching aim for the funders is:

Reduction of the incidence of *Campylobacter* infection in humans

through reductions in:

- the level of the bacterium in farm-animal hosts
- the potential for cross-contamination throughout the food chain

This strategy focuses on the issue from the UK perspective and practices within the industry that are particular to the UK situation, however outputs of UK research will also have wider international relevance and impact.

[1] http://www.food.gov.uk/multimedia/pdfs/foodchainhazardsimpacts

Summary of research priorities:

Understanding current practice and potential intervention strategies

- High-quality baseline data and regular monitoring of poultry
  - *High-quality baseline data*
  - *Regular measurements of Campylobacter levels in poultry*
- Comparison of the different on-farm and in-factory practices that affect *Campylobacter* incidence in poultry
- Understanding the effect of water treatment, feed regimes and supplements for poultry
- Studies around potential interventions in poultry transport/slaughter house/factory practices
- Quantitative modelling of interventions
  - On-farm and processing,
  - Catering, retail and the home
- Human behaviour:
  - On-farm and in production processes
  - Domestic and commercial preparation and cooking practices

The biology of the host and pathogen

- Predictive modelling of the system
- How the bacterium survives in the food supply chain
- Colonisation in the chicken and the chicken immune response
- Increased understanding of the role of microbiota of the chicken gut
- Development of bacteriophage, bacteriocins and other new anti-microbials
- Development of greater resistance to *Campylobacter* colonisation in chickens
- Underpinning the potential for a cost effective chicken vaccine(s)

Development of novel detection and diagnostic tools, and resources for *Campylobacter* research

- The development of a rapid, on-farm test for *Campylobacter*
- A strain bank to assist in understanding the genetic diversity of the bacterium

1 Background

The strategy

1.1 The purpose of this strategy is both to articulate the importance for the funders to tackle *Campylobacter*[2] research in a coordinated and coherent way, and to provide researchers and the industry with a clear list of research priorities in order to focus and stimulate their efforts around common goals.

1.2 This background section summarises the wider food policy and public health context for this strategy, including some of the strategic drivers for the individual funders.

1.3 The main theme running throughout this strategy is the need for the funders to coordinate and collaborate in order to deliver research most effectively. This need for joined-up working applies more broadly than *Campylobacter* and is a key principle of the government's Food Research and Innovation Strategy[3]. The funders already work closely in this area and this strategy aims to build on and enhance existing joint activities.

1.4 The UK public funders of *Campylobacter* research currently spend more than £4 million per year to address basic, applied, strategic and policy related research. Each has its own role, remit and research priorities, but all pursue high quality research that provides sound scientific information on which to base government policies and advice for industry and consumers. Current constraints on public funding give extra impetus to coordinate more effectively and gain maximum value from each funder's investment of limited resources.

1.5 The aim therefore of this strategy is to provide a new focus in developing joint priorities between the main UK public funders, in consultation with the industry, to help deliver coherent and coordinated research. To deliver this joint strategy some priorities will be primarily for a single funder to take forward, while most others will require joint activity, particularly where cross-disciplinary studies are needed.

1.6 This strategy must be seen in a wider international context both in the range of challenges facing us in food security and the global nature of the food supply chain. *Campylobacter* is a global problem and the UK funders work closely with international agencies, especially those in the EU, to address issues of joint interest. This strategy focuses on *Campylobacter* from the UK perspective with practices within the industry that are particular to the UK situation. The UK research base is well placed to conduct this research and deliver the knowledge and technologies that can be exploited by the UK industry, but outputs of UK research will also have wider international relevance and impact.

UK Government food policy

1.7 Early in 2010, the UK Government published its food policy strategy, (*Food 2030*)[4], aiming to address the challenge of achieving a more sustainable food supply by 2030. The vision for a sustainable and secure food system by 2030 includes food that is produced, processed and distributed to feed a growing global population, in ways that protect food safety and promote high standards of animal health and

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[2] For the purpose of this strategy *Campylobacter* refers to both *Campylobacter jejuni* and *Campylobacter coli,* unless stated otherwise.
[3] http://bis.gov.uk/assets/biscore/goscience/docs/c/cross-government-food-research-strategy.pdf
[4] http://www.defra.gov.uk/foodfarm/food/pdf/food2030strategy.pdf

welfare and ensure that the public feel confident that food is safe.

1.8 The food strategy (*Food 2030)* identified the importance of research and innovation in underpinning delivery of the Government's policy objectives and stressed that a coordinated Government approach is required to deliver this, including close working with the devolved administrations. To achieve this a UK Cross-Government Food Research and Innovation Strategy[5] was developed, led by the Government Chief Scientific Adviser Professor Sir John Beddington, to provide an overarching government framework for food research and innovation across the UK. The research strategy highlighted the need for funders to coordinate efforts to address the challenges in the food system, among them food safety, with *Campylobacter* in particular*,* as one of the key research targets.

1.9 BBSRC, FSA and Defra organised a three-day *Campylobacter* strategy workshop in October 2009 which brought together basic, strategic and applied researchers with representatives of key parts of the food supply chain (from production to consumer), to explore and prioritise research that would lead to practical outcomes and appropriate interventions in the control of *Campylobacter*. The workshop informed the development of this joint strategy document.

1.10 The workshop highlighted recent advances and gaps in understanding *Campylobacter,* in addition to issues faced by each component of the production to consumer food supply chain in developing *Campylobacter* control measures. It was apparent that there is a need to ensure that the advances in the understanding of *Campylobacter* biology and infection are translated into interventions to control colonisation and infection in farmed animals and in humans.

1.11 This strategy is timely, given the increased recognition across government and the public of the importance of a sustainable and safe food supply. The potential long-term cost savings in reducing the incidence of *Campylobacter* represent a significant financial incentive for both public and private sectors. More widely the EU has identified *Campylobacter* as an important issue and therefore a strong driver for action is the potential for future cross-EU targets for *Campylobacter*.

Food-borne zoonoses and public health

1.12 Food-borne zoonoses, especially diarrhoeal diseases, are an important cause of morbidity and mortality world-wide. The World Health Organisation estimates that each year over two million people die from diarrhoeal diseases, many of which are acquired from eating contaminated food[6]. The most important food-borne infections in the world are caused by bacteria such as *Campylobacter, Salmonella*, *Escherichia coli* and *Listeria* and by viruses. Although most of these diarrhoeal deaths occur in developing countries, food-borne zoonoses are not limited to these countries. The annual cost of food-borne illness in England and Wales has remained fairly stable since 2005, at around £1.5 billion[7], although this is potentially a conservative figure. Acute food-borne illnesses are estimated to cost the USA $152 billion per year in healthcare, workplace and other economic losses[8].

1.13 The European Food Safety Authority (EFSA) published, "The Community summary report on trends and sources of zoonoses, zoonotic agents and food-borne outbreaks

[5] http://bis.gov.uk/assets/biscore/goscience/docs/c/cross-government-food-research-strategy.pdf
[6] http://www.who.int/gfn/general/documents/GSS_STRATEGICPLAN2006_10.pdf
[7] http://www.food.gov.uk/multimedia/pdfs/publication/annualscientistrep0909.pdf
[8] http://www.producesafetyproject.org/media?id=0009

in the European Union" in 2008 [9]. This report provides information on emerging or re-emerging zoonoses; it is also a tool to evaluate whether the Community or national control measures are effective in reducing the occurrence of zoonotic agents. The report highlights that in 2008, Campylobacteriosis continued to be the most commonly reported gastrointestinal bacterial infection in humans in the European Union, with an estimated[10] 2-20 million clinical cases [11].

1.14 The recently published baseline survey from EFSA[12] reported that:

> *Campylobacter* was detected in pooled caecal contents of broilers and on broiler carcasses in all 26 of the participating Member States and the two non-Member States[13]. Overall the prevalence of *Campylobacter*-colonised broiler batches was 71% and that of *Campylobacter*-contaminated broiler carcasses was 76%. Member State prevalence varied from 2% to 100% and from 5% to 100%, for caecal contents and carcasses respectively. About two-thirds of the *Campylobacter* isolates from the broiler batches as well as those from the broiler carcasses were identified as *Campylobacter jejuni*, while one-third was *Campylobacter coli*. A few were identified as other *Campylobacter* species.

This indicates that *Campylobacter* is widespread in the food supply chain across Europe.

1.15 The European Commission has asked the EFSA Working Group on *Campylobacter* in broiler meat (which reports to the Scientific Panel on Biological Hazards) to provide an update and quantification of the risk posed by *Campylobacter* in broiler meat. In particular, EFSA is asked to propose potential performance objectives and/or targets at different stages of the food chain in order to obtain e.g. 50% and 90% reductions in human Campylobacteriosis in the EU caused by broiler meat consumption or cross-contamination.

1.16 From the UK perspective, a survey[14] carried out by the Food Standards Agency (FSA) for *Campylobacter* and *Salmonella* testing in chicken on retail sale in the UK between May 2007 and September 2008 highlighted the prevalence of these food-borne pathogens in chicken. The survey reported that *Campylobacter* was present in 65% of the fresh chicken samples tested, based on a methodology that potentially underestimates levels[15] compared to some other methodologies.

Funders' individual strategies

1.17 Each funder has its own specific role, remit and objectives relating to food-borne disease. These are briefly outlined below and set out in more detail in Section 4.

FSA

1.18 The FSA has highlighted that in the coming years one of its main priorities is to reduce food-borne diseases in the UK. This is reflected in the FSA's new Science and Evidence Strategy 2010-15[16] and Strategic Plan 2010-2015[17] which states that

[9] http://www.efsa.europa.eu/en/scdocs/scdoc/1496.htm
[10] 190,566 confirmed laboratory cases, though reporting regimens differ in each member state
[11] http://www.efsa.europa.eu/en/efsajournal/scdoc/1437.htm
[12] http://www.efsa.europa.eu/en/scdocs/scdoc/1503.htm
[13] One member state did not participate
[14] http://www.food.gov.uk/news/newsarchive/2009/oct/chicksurvey
[15] Level for the purpose of this strategy is defined as the microbial count
[16] http://www.food.gov.uk/aboutus/publications/busreps/strategicplan/

food-borne disease will be reduced using a targeted approach, tackling *Campylobacter* in chicken as a priority. In order to achieve a substantial reduction in *Campylobacter*, FSA is implementing a *Campylobacter* Risk Management Programme[18,19]. The Programme encompasses a range of projects targeted at different points across the food chain, from farm to fork. To measure progress on the effectiveness of the Programme a new target for the reduction of levels of *Campylobacter* in chicken will be set and published by December 2010, to be achieved by April 2015. The target will be set and achieved through stakeholder engagement and partnership working.

1.19 Although the FSA target will be focussed on the reduction of levels of *Campylobacter* in chicken in the UK, the ultimate aim is to reduce levels of human infection. Therefore the *Campylobacter* Risk Management Programme will be complemented by other work to improve public awareness and effective use of messages about good food hygiene practice at home and in catering establishments.

BBSRC

1.20 BBSRC is the main UK funding agency for research in the life sciences, with a remit that includes microbiology, animal science (including animal disease) and human diet and health. Its vision[20] is to foster a world-class biological science research community in the UK, at a time when we are moving towards a more integrated and collaborative approach to research in the biosciences. The BBSRC Strategic Plan 2010-2015 – The Age of Bioscience[21] highlights priorities in research areas that are directly relevant to food safety. It notes that "BBSRC will support fundamental and comparative studies of human, animal and microbial biology leading to potential new antimicrobial drugs and to improvements in both human and animal health in the context of 'one biology, one health"[22].

Defra

1.21 Defra's overarching purpose is to secure a healthy environment, including a sustainable, secure and safe food supply, in which current and future generations can prosper. An Evidence Investment Strategy has recently been published[23] which highlights the food chain as one of the areas for increased investment needs. Defra funds zoonotic and food-borne disease under the auspices of its Animal Health and Welfare programme. The Animal Health and Welfare Strategy for Great Britain (2004)[24], and associated Evidence Base document, sets the framework for Defra's work to improve animal health and welfare of kept animals in the UK, including working in partnership with farmers to reduce levels in animals of zoonotic diseases which might impact on human health.

Coordination across funders

1.22 Microbiological research in the area of food safety has been coordinated through the

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[17] http://www.food.gov.uk/aboutus/publications/busreps/strategicplan/
[18] http://www.food.gov.uk/multimedia/pdfs/board/fsa100504v2.pdf
[19] http://www.food.gov.uk/consultations/consulteng/2010/foodbornediseasestrategyeng
[20] http://www.bbsrc.ac.uk/web/FILES/Publications/bbsrc_vision.pdf
[21] http://www.bbsrc.ac.uk/publications/policy/strategy/strategic-plan-index.aspx
[22] The "One Health" concept seeks to link multiple disciplines (medical, veterinary, biology, virology, epidemiology, immunology etc.) by drawing on a common pool of knowledge between these sectors in order to improve the health and well being of animals and humans
[23] http://www.defra.gov.uk/evidence/science/how/strategy.htm
[24] http://defra.gov.uk/foodfarm/policy/animalhealth/index.htm

Microbiological Safety of Food Funders Group (MSFFG) [25], which includes BBSRC, FSA, Defra, DH and DARD-NI amongst others. The Group was established in 1998 with a remit to co-ordinate UK publicly funded R&D on the microbiological safety of the food chain with a view to informing the R&D effort, identifying gaps and overlaps, and providing technical reports as appropriate. This strategy builds on the past coordination and collaborative activities of this and other bodies.

1.23 Existing coordination has enabled joint funding of activities where one funder may have strategic interests in another funder's research. For example, Defra and FSA contribute to BBSRC's Government Partnership Award scheme by providing co-funding for responsive mode grants that have a strong policy relevance. The UK Cross-Government Food Research and Innovation Strategy[26] sets out principles for enhancing coordination among public research funders.

1.24 The Global Food Security programme, launched in 2010, aims to coordinate the delivery of food research funding among five Research Councils, five Government departments and the Technology Strategy Board. Most of the partners in this *Campylobacter* strategy contribute to the Global Food Security programme, which includes food safety as an important component. The programme is currently under development, but it is expected that it will be aligned with, and complementary to, relevant and related funders' strategies, including this one.

Partnerships with industry

1.25 There is awareness amongst the businesses involved in the food supply chain (producers, processors and retailers) that work needs to be done to control *Campylobacter* colonisation and contamination. Efforts already being made to identify and implement measures to control *Campylobacter* involve the British Poultry Council (BPC), the FSA, Defra and the British Retail Consortium, through a Joint Government/Industry Working Group on *Campylobacter*. The BPC has said "While this group is mainly focused, at this stage, on possible measures during processing, there is a clear need for more scientific research, particularly on routes of transmission, to identify effective prevention and controls at the farm level."

1.26 There is a clear need for industry, research scientists and policy makers to continue to work together to enable more effective control measures to be developed, based on excellent underpinning science, in order to meet the needs of industry and the consumer.

Development of this strategy

A challenge-led approach

1.27 A volume of research relating to *Campylobacter* is supported in the UK. The recent rapid increase in the availability of genome sequences and comparative genomic data has increased our understanding of the epidemiology and metabolic capacity of this organism. Despite such advances, *Campylobacter* remains a poorly characterised microorganism and many aspects of *Campylobacter* biology remain unexplained.

1.28 The workshop held in 2009 (see Section 6) highlighted a number of challenges that need to be addressed to develop *Campylobacter* control measures across the food

[25] http://www.msffg.org.uk/
[26] http://bis.gov.uk/assets/biscore/goscience/docs/c/cross-government-food-research-strategy.pdf

chain. These range from fundamental biology of both the bacterium and the chicken, and exploiting the latest genomic and mathematical tools, to developing rapid in-field detection methods and improving biosecurity. These challenges and the underpinning research required to resolve them form the basis of this strategy, outlined in a series of priorities in Section 2.

Wider perspective

1.29 Section 6 highlights the 30+ potential priorities identified at the joint strategy workshop held by funders in 2009 and how these were rationalised into the priorities in this strategy. All of these research targets have the potential to reduce levels of *Campylobacter*. In addition there may be other important research areas not identified in this strategy, especially those emerging from recent findings. This strategy is not intended to constrain research in other areas but attempts to prioritise the funders' research based on the current state of knowledge and the views of industry and policymakers.

1.30 In 2009 over 300,000 tonnes of poultry were imported to the UK and this strategy cannot directly affect *Campylobacter* levels in any of these sources. *Campylobacter* is a worldwide problem and the UK funders are working closely with other agencies, especially in the EU, to share data and best practice to reduce *Campylobacter* levels globally. In addition the results of high quality research funded to address the priorities in this strategy will receive international attention through publication and dissemination through various networks.

1.31 This strategy is based on current UK regulations and legislation. Therefore it is not the intent of this strategy to address reduction methods used overseas such as chlorination or other anti-microbial agents; nor does it consider interventions known to be opposed by consumers, e.g. irradiation.

1.32 It is well established that poultry is the most significant source of *Campylobacter* in the food chain, in the UK, possibly responsible for ~70% of the cases[27], although the exact percentage is often disputed. There are multiple other sources of *Campylobacter,* both food-borne and environmental, but currently there is no evidence that intervention in any other single source would have as significant an effect as interventions in poultry. This strategy therefore focuses on poultry but the funders recognise that, as levels in poultry are reduced, non-poultry sources may become increasingly important for research, especially if a particular single non-poultry source is discovered to be a high risk factor for human infection.

1.33 Outside the food supply chain *Campylobacter* is an environmental risk both to humans and animals, especially from contaminated water, but such studies are outside the scope of this strategy. *Campylobacter* is a problem not just in the developed world but is a significant disease in the developing world, which again is outside the scope of this strategy due to its UK focus. The basic knowledge gained through implementation of this strategy will, however, underpin future research in both of these areas.

Delivery mechanisms for this strategy

1.34 This strategy has been formulated jointly by the main UK research funders in recognition of the importance of a coordinated, coherent approach to tackling the problem of *Campylobacter*. However, it is important to note that although the funders

[27] http://www.efsa.europa.eu/en/scdocs/scdoc/1437.htm

have agreed a joint approach this does not necessarily mean that activities will have joint funding from a “common pot”. The funders each have distinct roles and remits and support research for different reasons: ranging from underpinning the scientific research base through to addressing specific policy needs. Individual funders have specific remits, eligibility rules and funding constraints that may limit joint funding, but these differences do not preclude harmonization of activities. Funding calls therefore may be more appropriately undertaken by a specific funder or subset of funders, but all activities will be implemented in consultation with other relevant partners to ensure a coordinated overall approach.

1.35 Irrespective of any targeted funding calls relating to this strategy, opportunities will exist for appropriate fundamental underpinning work in responsive mode in the relevant Research Councils and new work may be commissioned by government to underpin regulatory changes or new policy requirements.

Revision of the Strategy

1.36 The funders have regularly met to discuss and review all aspects of microbial food safety through the MSFFG[28]. It is anticipated that this strategy will be reviewed and refreshed, as necessary, by MSFFG or other appropriate body to ensure it takes account of developments in the sector. In addition to such scientific and policy scrutiny, the success and impact of the joint working between the funding partners will be considered by the Food Research Partnership, chaired by the Government Chief Scientific Adviser[29].

[28] www.msffg.org.uk
[29] http://www.dius.gov.uk/go-science/science-in-government/key-issues/food

2 Joint priorities for research on *Campylobacter* in the food supply chain

2.1 Within the UK many of the challenges in *Campylobacter* research cut across government departments and Research Councils. Joint priorities and coordinated funding will both avoid potential duplication of effort and ensure more effective delivery of current research spend. This strategy is focused on the main source of human *Campylobacter* infection, i.e. from the food supply chain, though it is acknowledged that there are other potential sources of infection.

2.2 Fundamental to this strategy is the need for collaboration and coordination between funders, the industry and researchers, driven by the need for a multidisciplinary approach to the problem. Strong links to industry both ensure research is grounded in "real world" situations and accelerate the translation of the research, thus improving its impact.

2.3 The delivery of these priorities will require a cross-funder multidisciplinary approach involving microbiologists, immunologists, and modellers working with economists and social scientists and building on data collected through working with veterinarians, medical practitioners and the industry.

2.4 This strategy has gone beyond the identification of common aspirations and has articulated clear priorities which the funders will aim to deliver in a coordinated and collaborative way. Further background to how these priorities were derived is in Section 6. The priorities are based on a snapshot of the current state of play in this field and new priority areas may arise for the funders during the lifetime of this strategy.

> The overarching aim for the funders is:
>
> **Reduction of the incidence of *Campylobacter* infection in humans**
>
> through reductions in:
> - the level of the bacterium in farm-animal hosts
> - the potential for cross-contamination throughout the food chain

2.5 There is no single "magic bullet" to deliver the overarching aim and it is likely that multiple, research-based interventions will be required across the food chain. For this reason a variety of priorities have been identified ranging from underpinning bioscience to identification and implementation of best practice. The following priorities are not in any order of importance and are designed to highlight to researchers and industry the areas where new research is required, or where a new assessment of available data is needed. This approach is intended to identify which interventions will yield the most timely and cost-effective results, within the bounds of current regulation and to the acceptance and benefit of consumers. The priorities are presented in 3 sections:

- understanding current practice and potential intervention strategies
- the biology of the host and organism
- the underpinning tools and resources required

Summary of research priorities:

Understanding current practice and potential intervention strategies

- High-quality baseline data and regular monitoring of poultry
  - *High-quality baseline data*
  - *Regular measurements of Campylobacter levels in poultry*
- Comparison of the different on-farm and in-factory practices that affect *Campylobacter* incidence in poultry
- Understanding the effect of water treatment, feed regimes and supplements for poultry
- Studies around potential interventions in poultry transport/slaughter house/factory practices
- Quantitative modelling of interventions
  - On-farm and processing,
  - Catering, retail and the home
- Human behaviour:
  - On-farm and in production processes
  - Domestic and commercial preparation and cooking practices

The biology of the host and pathogen

- Predictive modelling of the system
- How the bacterium survives in the food supply chain
- Colonisation in the chicken and the chicken immune response
- Increased understanding of the role of microbiota of the chicken gut
- Development of bacteriophage, bacteriocins and other new anti-microbials
- Development of greater resistance to *Campylobacter* colonisation in chickens
- Underpinning the potential for a cost effective chicken vaccine(s)

Development of novel detection and diagnostic tools, and resources for *Campylobacter* research

- The development of a rapid, on-farm test for *Campylobacter*
- A strain bank to assist in understanding the genetic diversity of the bacterium

Understanding current practice and potential intervention strategies

High-quality baseline data and regular monitoring of poultry

High-quality baseline data

2.6 Baseline data are essential to establish the effectiveness of any large-scale interventions, and to determine whether long-term strategies are delivering a reduction in *Campylobacter* levels across the food supply chain. Numerous baseline studies have been performed over the years, but as new knowledge of the risk factors associated with *Campylobacter,* colonisation, growth and survival emerge it is important to establish whether the current baseline data are fit for purpose and if new data are required. Baseline data should:

- be collected from across the food supply chain, and include data on human infections
- have full coverage of all established and emerging risk factors
- include species/strain identification using advanced, accredited typing methods
- be of sufficient quality to underpin quantitative modelling studies
- strengthen animal and public health surveillance systems
- provide a greater volume of high quality data with associated metadata (e.g. source attribution, strain, culturing and typing used etc.) pertaining to proven risks which are linked to the disease process.

2.7 If current baseline data are not found to be of sufficient quality or breadth further studies may be required.

Regular measurements of Campylobacter levels in poultry

2.8 Although it is not usually funded through research projects, regular measurement of *Campylobacter* in flock, carcass and retail samples provide essential data for detecting changes in levels at different points in the food supply chain and enable policy makers to understand the impacts of interventions. Regular measurements can also detect any changes in levels due to new production/processing practices, and allow for the incorporation of spatio-temporal data in modelling studies. Data from regular monitoring will underpin the long-term evaluation of many of the projects funded to deliver this strategy.

Comparison of the different on-farm and in-factory practices that affect *Campylobacter* occurrence rates in poultry

2.9 *Campylobacter* is a complex organism and it will take a number of years to understand fully the risk factors associated with colonisation and infection, and to develop a comprehensive risk management strategy to prevent contamination of the

food-chain and ultimately human food-borne infections.

2.10 In the short term, current biosecurity measures and interventions in place in the UK need to be evaluated for their cost effectiveness in reducing *Campylobacter* levels. Studies should exploit existing data, where it is of sufficient quality.

2.11 Knowledge of the variability of production processes and practice is essential. Best practice needs to be identified and shared widely through knowledge exchange mechanisms. Complementary data and lessons learnt from EU and other overseas projects will also need to be collated. In the longer term, it is likely that new interventions will emerge as more underpinning research on risk factors is undertaken. New interventions designed for reducing *Campylobacter* are also likely to be beneficial for preventing other animal and food-borne diseases.

Understanding the effect of water treatment, feed regimes and supplements for poultry

2.12 Research indicates that there are strong interactions between the gut environment and levels of *Campylobacter* in the animal host e.g. it is known that pH affects *Campylobacter* levels in the gut in chickens. In addition there is a greater body of evidence on the importance of diet in the regulation of the gut environment and microbiota. Simple modification of the diet, e.g. addition of organic acids or probiotics, has shown a potential influence upon *Campylobacter* levels. Greater understanding of *Campylobacter* nutritional requirements and colonisation might identify critical periods of *Campylobacter* colonisation requiring essential nutrients, thus allowing appropriate timing of interventions.

2.13 It will also be important that any feed modifications aimed at reducing *Campylobacter* levels have no net adverse effects on the health, welfare or productivity of the animal host e.g. increased stress to the bird might have a more negative effect on *Campylobacter* control than any positive effect of the feed modification.

2.14 Contaminated water is a known risk factor for *Campylobacter* on-farm and is a potential source of initial colonisation on-farm, especially from untreated sources or through transmission by contaminated drinking lines. Different water treatments have been tried in other countries, including addition of organic acids, but can have deleterious consequences such as supporting formation of biofilms. In-line UV treatment has been successfully implemented with relatively low costs. The importance of water as a source of initial *Campylobacter* colonisation and its potential to increase the rate of infection in the UK context, and the cost / benefits of any intervention, needs to be better understood.

2.15 An understanding of the underlying science behind the effects of diet and health on the gut environment is required to determine the likely effectiveness of such interventions. Although some of the above approaches are potentially attractive as low cost interventions, it is unlikely that they will achieve complete control of *Campylobacter* levels. They must therefore be considered alongside other possible approaches.

Studies around potential interventions in poultry transport/slaughter house/factory practices

2.16 For slaughter house hygiene and biosecurity it will be essential to examine whether current biological and engineering interventions, and supporting aids e.g. the

slaughterhouse hygiene tool[30], have had any success in reducing *Campylobacter* in final retail products or in reducing cross-contamination of carcasses in the slaughterhouse and during processing; and what the cost-benefit is of these interventions, if known. It is also important to identify the effect of the mechanical processes on contamination, such as line speed and evisceration equipment, and whether cost effective modifications are possible, or practicable. It is also important to facilitate and evaluate the cost-effectiveness of some new interventions, such as steam, hot water, organic acids, treated processing water, decontaminants and other antimicrobial treatments, in an industrial setting.

2.17 One of the factors that will need to be understood is the impact of on-farm interventions and their knock-on effects on the slaughterhouse environment and in processing. It may be possible that interventions post-farm are cost effective only for highly contaminated flocks, and reduction of contamination levels on-farm might change the type of post-farm interventions required. One significant potential consequence of the reduction of levels on-farm, or more importantly an increase in the number of *Campylobacter*-free flocks, is that slaughter houses could channel/ schedule flock slaughter batches based on reliable prevalence data, thus reducing the potential for cross-contamination and the need for further antimicrobial interventions. Regular monitoring and risk management programmes will be essential here.

Quantitative modelling of interventions

2.18 Semi-predictive models for growth and survival of food-borne pathogens are publicly available through initiatives such as ComBase[31]. These models provide industry, government scientists and researchers with basic tools to predict pathogen behaviour in response to changes in food formulation and storage conditions. Whilst models are available for most food-borne pathogens, there is a paucity of similar models for *Campylobacter*. There is great potential to use predictive modelling for *Campylobacter* growth and survival over the whole food supply chain.

2.19 Although it is attractive to have a complete systems model of the food supply chain, the behaviour of individuals has a significant influence by introducing additional variability. In practice it is probably easier initially to model the components separately including: on-farm; during transport, in the slaughterhouse, during processing, in-catering, and in the home. Ultimately the goal should be to combine these models to give a more complete and accurate systems model. Additional models would assist in understanding the additive or reductive effect of practices at each stage. In particular, high-quality experimental tools can assist in considering the impact of control options and provide support to decision making by the relevant regulatory authorities.

2.20 Systems modelling approaches to biological problems have significantly advanced in recent years, but the core principle of a systems approach is the ability to test models and refine them according to experimental data. It is therefore essential that modellers have access to data from farm-scale and on-farm intervention studies in order to test and refine their models. This will require engagement with industry in order that the interventions are based on real systems and deliver reduced levels of *Campylobacter* in relatively short timescales.

2.21 Improved knowledge of the number of *Campylobacter* cells required to establish colonisation, infection and transmission between co-housed birds in a commercial

[30] http://www.ukmeat.org/FSAMeat/NewMethod.aspx
[31] www.combase.cc

setting is needed to underpin modelling. The levels of *Campylobacter* in different locations in the chicken can also have important implications for cross-contamination and human infection risk, since infection of deep tissue is likely to be more difficult to remove than surface contamination. Greater knowledge is also needed of the number of *Campylobacter* infective units required to cause human infection in a range of possible patients.

On-farm and processing

2.22 On-farm and processing intervention data are variable in quality and initial modelling has shown a number of interacting factors linked to colonisation and high levels of infectivity, suggesting potential targets for interventions. However, key to these models is the quality of the data and associated metadata. For example temperature is a correlated risk factor, but lower in-barn temperatures might be due to open air cooling, which exposes the birds to insect vectors, or air conditioning, which changes moisture and air circulation. It is essential, therefore, that modellers have access to robust data and that models use the latest quantitative analysis to identify the most important components from the many potential risk factors.

Catering, retail and the home

2.23 *Campylobacter* is present on most raw poultry meat entering kitchens and poor hygiene can lead to cross-contamination of surfaces, utensils and ready-to-eat foods. Research is needed to develop robust predictive modelling tools for *Campylobacter* growth and survival in food and on surfaces. Such work should also take into account the potential for growth and survival following cross-contamination in the kitchen environment.

Human behaviour

On farm and in production processes

2.24 The “human factor” is widely recognised as a risk in catering and the home but is also an important factor on-farm and throughout the food supply chain. There is a range of incentives/motivators for farmers to implement and maintain biosecurity and intervention measures. Studies have shown that farmers are willing to make changes provided they bring benefits and are of minimal risk to their business.

2.25 Social science research is required to identify farmers’ motivation to take up interventions and to understand how policy makers should communicate with farmers to disseminate best practice and to influence behavioural change. Such research would complement baseline studies and may help to reveal why some farms stay *Campylobacter*-free while others do not. The research could lead to appropriate educational tools/literature to help farm managers and workers (if required), to understand the societal benefit of reduced *Campylobacter* on farms, and to give clear identification of the best interventions to achieve this. In addition, motivation studies could consider financial incentives (e.g. premiums for *Campylobacter*-free flocks or penalties for high levels) and their potential effect on levels and overall cost-benefit to the industry. Financial interventions must be placed in the wider context of the industry, and all the potential behavioural implications fully understood before implementation. Other incentives used in some other countries have included “name and shame” policies for the worst performing farms or slaughter houses. Consumer attitudes to interventions are also important to understand e.g. through citizen forums, as no farmers or producers will implement changes that may alienate retailers, or ultimately consumers.

2.26 There are currently no direct regulatory forces motivating retailers to control or reduce *Campylobacter* levels. Pressure on retailers can have a beneficial net effect on the whole food chain, as retailers demand changes from processors/producers who then demand changes from their farmers. Examples from other countries of regulations targeted at retailers have included allowing retailers to sell fresh chicken only from *Campylobacter*-free flocks, publishing retailers' *Campylobacter* levels, and additional labelling on higher risk carcases, etc. Understanding the impact of these interventions and their relevance to UK retailers and producers will be important.

2.27 Ultimately the goal of any interventions must be to reduce the levels of *Campylobacter* in food and this will require clear guidance on how to achieve this.

Domestic and commercial preparation and cooking practices

2.28 Studies have shown that consumers/caterers are not well informed about the specific risks of *Campylobacter* and generally understand broader messages, such as proper handling and cooking of chickens. These alone should in principle be sufficient to minimise *Campylobacter* infections, but given the number of cases every year in the UK it is clear that merely informing consumers is not sufficient, and reduction of the load on and in raw meat is also required. Behavioural data must be based on the UK consumer and caterer, taking into account cooking practices, the cuts of chicken used and necessary handling of these, and the use of precooked and commercially prepared foods.

2.29 Research is needed to understand how long-term behavioural change can be achieved across the food supply chain, but particularly amongst producers and consumers. It is also important to understand producer and retailer behaviour to ensure that identified interventions are properly applied. The implications of these changes to the food supply chain also need to be understood. Similarly, better understanding is needed of how to influence consumers to apply safe food handling practices consistently - especially consumers more at risk from complications due to *Campylobacter* infection.

The biology of the host and pathogen

2.30 The development of effective prevention and intervention strategies is severely hampered by our relatively poor understanding of *Campylobacter* biology, compared with some other food-borne pathogens. Elucidating the molecular mechanisms underlying physiology, metabolism, stress adaptation, infection by and virulence of *Campylobacter,* and its interactions with its hosts, will help informed decision making for the reduction and/or elimination of *Campylobacter* in the food chain.

Predictive modelling of the system

2.31 Many complex biological systems in both the host and pathogen contribute to *Campylobacter* pathogenesis. Host-pathogen interactions add further complexity to this. Basic understanding of each of the main components of the system is not only intellectually challenging but essential if some of the long-term challenges in reducing colonisation, infection, and spread and survival on meat are to be solved. However in order for the basic research to be translated effectively and in a timely manner it is essential to study how these components interact in the system as a whole.

2.32 A systems biology approach to *Campylobacter* will require interdisciplinary research involving microbiologists, immunologists and mathematical modellers working in collaboration to generate predictive models of *Campylobacter* colonisation and infection. More refined models of the systems will allow for a greater understanding of why certain interventions work, and the ability to identify new control mechanisms.

How the bacterium survives in the food-supply chain

2.33 One of the problems with controlling *Campylobacter* is its persistence in the environment. This has implications for initial infection of livestock, cross-contamination on-farm, in-transport and in the slaughter house, and contamination in catering and in the home.

2.34 One of the challenges on-farm is in understanding the effect of potential vectors e.g. protozoa, insects, wild birds, small mammal pests, or the contributing presence of other livestock in the vicinity of the barn. The risks factors for each of these are not fully understood but general biosecurity principles should attempt to minimise interactions of farmed animals with all pests. This clearly becomes more difficult when using non-contained farming systems.

2.35 *Campylobacter* can persist in soil, water and on surfaces. Faecal matter is a significant source of contamination, but effective cleaning regimes and good biosecurity should reduce the risk. Additional underpinning research is required to understand the conditions required for the organism to survive outside the host, especially in cleaner more bio-secure environments.

2.36 *Campylobacter* persistence on a variety of surfaces has significant implications for catering and retail operations and in the home. Further research is required to establish which surfaces provide lower risk of *Campylobacter* persistence, and which cleaning regimes and treatments can minimise persistence.

Colonisation in the chicken and the chicken immune response

2.37 Colonisation by *Campylobacter* and the consequential response by the chicken's immune system is complex, involving many factors both external and internal to the chicken. Initially, relatively robust/quick/cheap methods are needed to quantify host "resistance" at a phenotypic level before the necessary linkages to genetic mapping and selection can be undertaken. The influence and importance of chicken genetics is discussed in the section on breeding genetically resistant birds.

2.38 There is increasing evidence that links stress and immunosuppression in birds. Stressed birds are more highly colonised with *Campylobacter* and in such animals *Campylobacter* are more likely to spread from the gut and infect edible tissues. There is obvious synergy in understanding the interactions between *Campylobacter* colonisation, stress, immune responses and infections by other pathogens. The current practice of thinning (removal of some of the flock prior to the main slaughter) has been identified as a stressor, while the presence of other pathogens such as avian pathogenic *Escherichia coli* (APEC) is known to increase disease prevalence, and free-range birds on average have higher *Campylobacter* levels[32]. But few other factors linking stress and infection have been identified to date. Identification and reduction of stressors could aid cost effective reduction in colonisation.

2.39 *Campylobacter* induces an innate response by the chicken's immune system, and

[32] http://www.food.gov.uk/multimedia/pdfs/fsis0409.pdf

anti-*Campylobacter* antibodies can be measured post-infection/colonisation. However, since most infected/colonised birds do not show clinical signs or any associated immunopathology - and the induced innate response is small and limited in duration - *Campylobacter* appears to evade and/or subvert the chicken's full immune response. One possible mechanism for this is the flagellum, as strains of *Campylobacter* in which the flagellin glycosylation genes are knocked out induce immune responses in infected chickens similar to those seen with *Salmonella*. The flagellar secretion system is the co-opted route for the secretion of *Campylobacter* proteins that facilitate invasion of intestinal epithelial cells, potentially allowing immune evasion by *Campylobacter*. Research in these areas would deliver underpinning knowledge of the molecular interactions between *Campylobacter* and its avian host, and also may help to identify both selective breeding targets in the host and possible vaccine candidates.

Increased understanding of the role of microbiota of the chicken gut

2.40 The importance of gut microbiota (total microbial populations) for health and wellbeing is becoming apparent in all animals, including humans. In addition to aiding the animal's digestion, it is now being appreciated that gut microbiota perform important functions both in competitive inhibition of harmful bacteria and in control and stimulation of immune responses. In the case of *Campylobacter*, not only are chicken gut colonisation mechanisms potentially unique but the gut microbiota show great variability even among genetically similar birds. Understanding the effect of gut microbiota on both *Campylobacter* infection and colonisation is important in managing and preventing infections. Factors affecting microbiota range from diet, bird welfare, health and age, to the genetics of the host, and enhanced understanding of these factors would be relevant to research beyond *Campylobacter*. Identification and comparative analysis of microbiota from negative and positive flocks, and at the point of *Campylobacter* colonisation, would provide underpinning data to establish the links between microbiota and infection.

Development of bacteriophage, bacteriocins and other new anti-microbials

2.41 In many cases, bacterial infections of farmed animals can be managed or controlled through pharmaceutical interventions, although often these are subject to extensive regulatory control and are unpopular with consumers. In the case of *Campylobacter,* initial research has shown that bacteriocins can reduce infection. In addition some initial work on bacteriophage, in highly colonised birds, shows potential to reduce levels of *Campylobacter*. Research in these areas is still at an early stage and not well established enough to be implemented through a policy priority. Further understanding of the chicken immune response, *Campylobacter* biology and virulence, and the potential efficacy of these interventions is required. There is also scope to consider new anti-microbial treatments. Any treatments resulting from such research must comply with relevant regulations and be acceptable to consumers.

Development of greater resistance to *Campylobacter* colonisation in chickens

2.42 Availability of chickens with significant innate resistance to *Campylobacter* colonisation is one of the main long term goal for researchers and industry, since, once established, it would represent a safe, cost-effective solution. There is evidence in chickens that genetic variation confers greater resistance to *Campylobacter*, reducing (but not eliminating) levels of the bacterium in the chicken gut, by up to a

factor of four log values. Quantitative Trait Loci (QTL) analysis in inbred chicken lines has indicated that some of the resistance loci overlie known bacterial resistance genes. Such candidate genes should be followed up in the short term to associate specific alleles with resistance and to check that they segregate with resistance in commercial lines. Defining the impact of host genetics on transmission dynamics between co-housed birds (e.g. of susceptible vs. resistant lines) is a first step to confirm if selective breeding has potential. If successful, this would allow a targeted and rapid approach to breeding lines of poultry more resistant to *Campylobacter* colonisation and infection.

2.43 Further work to map resistance genes, coupled with using the latest methods that allow selection of genes throughout the whole genome, could be of long-term benefit to create chicken lines with multiple resistance. Using tools such as new generations of high density SNP panels (500k or more markers), candidate animals can be identified and used to select future generations of chickens with robust resistance and greatly reduced levels of *Campylobacter* colonisation.

2.44 In addition to following up candidate genes in the short term, QTLs should be investigated further to locate the causative genes and beneficial mutations. This research will require several years to generate the necessary crosses to give sufficient recombination to permit identification of candidate genes, and then further work to verify the association of a gene with the resistant phenotype in inbred and commercial lines.

2.45 This genetic research must be done in collaboration with industry since gene association studies must be implemented in poultry breeding programmes. It is likely that resistance to *Campylobacter* depends on multiple genes and the selection of resistant strains will depend on the identification of specific traits and candidate animals. It is highly unlikely that birds completely resistant to colonisation can be selected and therefore it will be essential to complement this work with other approaches to minimise induction, transmission and cross-contamination, including the potential for vaccination.

Underpinning the potential for a cost effective chicken vaccine(s)

2.46 In this section the funders have identified as a priority the need for some basic research that will underpin the development of possible future vaccines. The funders consider that a full-scale vaccine development programme is too high a risk at present to warrant support from public funds.

2.47 Vaccines can provide a safe and effective method to control pathogens in animals and humans - potentially leading to eradication of some diseases. Vaccine development is time-consuming and expensive, and requires significant underpinning knowledge of the host immune system, antigens, and an understanding of potential adjuvants.

2.48 To date, many vaccines against bacterial gut pathogens target a particular adhesin or toxin that the bacterium requires for pathogenesis. It is not yet clear whether *Campylobacter* has such potential targets. Most of the current attempts at a vaccine reduce colonisation by 1 or at most 2 logs per bird, which is low for a vaccine. Furthermore, chickens are usually slaughtered before 40 days of life, meaning that inducing protective immunity might be difficult. Some subunit vaccines can reduce *Campylobacter* levels by up to 4 logs, which may be significant in reducing human disease, and this technology should be investigated further. However, *Campylobacter* is very variable genetically so if a sub-unit approach were taken, it

might be hard to find a suitable antigen that would work against all types of *Campylobacter* and for a sufficiently long time.

2.49 Various *Campylobacter* candidate genes could be tested, both in isolation and in combination, as could the use of chicken immune function genes (such as cytokines) or molecules that would target the vaccines to dendritic cells, as vaccine adjuvants.

2.50 More extensive knowledge of the host and the pathogen, and understanding of the dynamics of colonisation, will be developed from work delivering many of the other priorities listed in this strategy. It is expected that basic knowledge will be gained of the potential for vaccines without the immediate need for a vaccine programme *per se,* thus mitigating the overall cost of a possible vaccine development programme in future.

2.51 For the above reasons a specific programme aimed at vaccine development has too high a risk of failure, and thus is not a current priority for the funders. However, given the potential benefits of a vaccine, it is important to undertake basic supporting research which will demonstrate vaccine feasibility or which may rule out certain approaches. Such research could include:

- Quantitative epidemiological modelling to establish the degree of vaccine efficacy required for effectively reducing the levels of colonisation in individual birds, and thus reducing overall levels in food; also how vaccination could be applied, coupled with cost-benefit analysis compared with other intervention approaches
- Research to understand chicken gut immunity in greater detail, pertaining to bacterial pathogens in general and *Campylobacter* in particular, using the latest antimicrobial immunology to identify intervention targets. This should build on the previous literature, but also be focused on gathering evidence on whether protective immunity against *Campylobacter* is ever really raised during natural infection. If it is, can it be manipulated to our own ends; if not, can we nevertheless produce protection artificially? This should be done in experimental systems, but it must also include an on-farm component so that the responses are studied in real birds, in real situations, with realistic inoculum sizes, building on existing data, or after new appropriate high quality research has been undertaken.
- Investigating the possibility of non-specific immune approaches, i.e. find ways of inducing non-specific innate immunity, used in conjunction with other approaches
- Research that investigates the molecular basis for how *Campylobacter* is successful in colonising the caecum.

2.52 Ultimately, vaccines have to be developed and implemented by industry. Even if a vaccine is technically feasible it must be cost-effective and therefore research programmes must interact with industrial partners if a successful vaccine is to be commercially viable. Some vaccine work is currently being explored by industry but it is not yet clear how successful these projects are. Further underpinning science (as outlined above) might increase the chances of current or future industrial projects succeeding.

Development of novel detection and diagnostic tools, and resources for *Campylobacter* research

The development of a rapid, on-farm test for *Campylobacter*

2.53 In order to compare current systems, improve biosecurity, and evaluate effectiveness of on-farm and slaughter house intervention studies, a rapid on-site test would be a considerable asset. Currently, to perform a reliable test requires culturing of the sample on agar plates over a number of days, in order to distinguish *Campylobacter jejuni* or *C. coli* from related non-pathogenic bacteria.

2.54 An immunologically based dip-stick test (similar to a pregnancy test) would be an attractive target. Such a test would rely on conserved antigens and it has not been established whether *Campylobacter* has conserved antigens, or that any conserved antigens are unique to the pathogenic strains of interest. Further research on *Campylobacter* surface architecture would elucidate whether this approach is feasible and would also underpin work on establishing if a vaccine based on surface antigen recognition is possible (see also section on vaccines, above).

2.55 An alternative to this approach would be a DNA probe-based assay to detect specific gene sequences. This type of assay can be expensive to develop, if it is possible at all. Given the high risk in pursuing such a test, feasibility data would be essential before any single approach was extensively supported by public funds.

2.56 Other approaches, such as measuring metabolites or excretion profiles have shown potential, but again further robust data would be required before this could be extensively explored.

2.57 Whichever approach is pursued, any viable test must be developed, and be validated to a high specification, in conjunction with industry in order to deliver a reliable product for use by researchers, regulators and industry.

A strain bank to assist in understanding the genetic diversity of *the bacterium*

2.58 One of the challenges in *Campylobacter* research is genetic variability, which extends beyond the strains isolated from different host animals, and therefore potentially every researcher may have access to different *Campylobacter* isolates. As further links between genetics and pathogenicity are elucidated it will be necessary to have access to strains with key genes of interest to test hypotheses. In addition, any new *Campylobacter* strains exhibiting novel properties need to be accessed by the wider community to make best utilisation of their discovery. *E.coli* research benefited from a collection (EcoR) of 72 *E. coli* strains assembled in 1984, which subsequently made a substantial contribution to the understanding of *E. coli* as a species. A similar resource for *Campylobacter* could be equally valuable, and potentially obtain broader usage if associated with a wider information database including e.g. sequence data, immunological properties, host data, colonisation data and pathogenic potential for humans. This resource would also have wider potential for underpinning work in evolutionary biology and population biology.

2.59 It would be important that any collection is sustainable and therefore it should aim to build on existing data and collections, and if appropriate, link to established resources. It would also be important that any such resource has strong links to fully exploit the latest high-throughput sequencing technologies and appropriate

bioinformatic resources to annotate and catalogue the collection.

3 Overview of current and recent funding

3.1 As noted in the introduction, the main purpose of this strategy is to coordinate existing spend in a more targeted way. A significant level of research relating to *Campylobacter* and the microbiological safety of food is supported in the UK, addressing both fundamental issues and those of more immediate application to animal and human health.

3.2 The table and figure below provide information on the expenditure of the main UK funders on food-borne zoonoses related research. The Wellcome Trust has been included for completeness though it is not a formal partner in this strategy. Data from MRC were not available.

Table 1: Expenditure on food-borne zoonoses research and surveys (2005-2010)

	FBZ research and survey funding in financial years (£ k)				
Organisation	**2005/06**	**2006/07**	**2007/08**	**2008/09**	**2009/10**
FSA	3,733	4,492	4,084	3,328	2,902
BBSRC	7,045	6,826	7,502	7,656	7,349[+]
DARD-NI	96	99	102	43	N/A
Defra	2,067[+$] (2,972)*	2,842[+$] (3,496)*	2,598[$] (3,460)*	2,180[$] (3,105)*	1,743[$] (2,642)*
DH[$]	83			2,275	1,176
Wellcome Trust	2,520	4,544	2,809	5,865	N/A
Scottish Government**	N/A	2,652	2,791	2,806	2,859

[+]estimated spend
[$] minus Antimicrobial Resistance (AMR) research; * including Antimicrobial Resistance (AMR) research
**This is the spend for Work Package 2.2 and is broader than food-borne zoonoses
[$]award not spend

3.3 Over the financial years 2005/06 to 2009/10 the public funders have spent over £20M on *Campylobacter* research. Details of the respective funders' annual spends can be found in the table below. Figures for spend in 2009/10 are reduced compared to previous years due to the delay of funding whilst this strategy was under development.

Table 2: Expenditure on *Campylobacter* research and surveys (2005-2010*)*

	Campylobacter research & survey funding in financial years (£ k)				
Organisation	**2005/06**	**2006/07**	**2007/08**	**2008/09**	**2009/10**
BBSRC	1,769	1,701	2,293	2,639	1,865*[+]
DARD-NI	96	99	102	43	N/A
Defra	577	1,051	979	794	510*
FSA[$]	1,393	1,398	973	680	194[*]
Wellcome Trust	8	2,059	140	491	N/A

Scottish Government do have specific spend on *Campylobacter* but the specific breakdown is not currently available
*spend held back for implementation of this strategy
[+]estimated spend
[$]updated to 2009 prices

4 Overview of funders

4.1 The majority of *Campylobacter* related research in the UK is supported by five public funders: the Biotechnology and Biological Sciences Research Council (BBSRC), the Department for Environment, Food and Rural Affairs (Defra), the Department of Health (DH), the Food Standards Agency (FSA) and the Medical Research Council (MRC). Additionally funding has also been provided by the Department of Agriculture and Rural Development in Northern Ireland (DARD) and the Scottish Government. Of these, the principal funders for *Campylobacter* research are BBSRC, FSA and Defra. The funders coordinate their activities through the Microbiological Safety of Food Funders Group[33], see also para 1.22.

4.2 A short summary of the funders was provided in Section 1. The individual funders have provided a more thorough overview on the following pages. Although the Wellcome Trust was not a partner in developing this strategy, the Trust's spend has been included for completeness because of its significant investments in this area.

Industry

4.3 The British Poultry Council and British Retail Consortium are working in partnership with the FSA to develop a Joint *Campylobacter* Reduction Action Plan. The action plan builds on existing research findings and experience within the UK poultry sector, and is further informed by the outcomes from FSA's international meeting on *Campylobacter* held in March 2010.

[33] www.msffg.org.uk

BBSRC

4.4 BBSRC is the UK's leading funder of academic research and training in the non-clinical life sciences in universities, institutes and centres. BBSRC's remit spans the microbial, plant and animal kingdoms, from molecules and cells to whole organisms, populations and systems. BBSRC's vision is for the UK to maintain its leading position in 21st century bioscience, promoting innovation and realising benefits for society within and beyond the UK.

4.5 BBSRC provides training in the biosciences, drives knowledge exchange and innovation, and enables public engagement around issues of societal importance.

4.6 *Campylobacter* research falls within two of BBSRC's three strategic research priorities identified in its Strategic Plan 2010-2015: Food security and Basic bioscience underpinning health. BBSRC supports research in areas that are directly relevant to food safety, such as animal health and welfare, genetics and genomics for improved animal breeding, and endemic and exotic animal diseases, including zoonoses. Fundamental studies leading to potential new antimicrobial drugs and improvements in human and animal health are supported in the context of "one biology, one health". [34]

4.7 BBSRC provides institute strategic research grants to the following:

- The Babraham Institute,
- Institute for Animal Health,
- Institute of Biological, Environmental and Rural Studies (Aberystwyth University),
- Institute of Food Research,
- John Innes Centre,
- Rothamsted Research,
- The Genome Analysis Centre and
- The Roslin Institute (University of Edinburgh).

The Institutes conduct long-term, mission-oriented research using specialist facilities. They have strong interactions with industry, Government departments and other end-users of their research.

For more information see: http://www.bbsrc.ac.uk

[34] http://www.bbsrc.ac.uk/publications/policy/strategy/strategic-plan-index.aspx

Defra

4.8 Defra funds applied research to inform legislation, policy, regulation, guidance, and to enable future responsiveness in Great Britain. This research contributes to a science base which improves public delivery of Government actions by ensuring that it is based on sound evidence.

4.9 Defra's Mission Statement, Public Service Agreements and Departmental Strategic Objectives can be found on the Defra website at:

http://www.defra.gov.uk/corporate/about/what/index.htm

4.10 The EU Zoonoses Directive (2003/99/EC) and the Zoonosis Regulation (2160/2003) requires Member States to engage in the risk assessment and management of zoonotic disease. Defra, as the competent authority in the UK, has a statutory responsibility to report on the monitoring of zoonoses and zoonotic agents in animals, food and feedstuffs and the results of food-borne outbreak investigations. Defra also has a duty to undertake activities to reduce the prevalence of certain zoonotic infections particularly at the primary production level. Presently, this applies to *Salmonella* in poultry and in future to pigs, but not to *Campylobacter*. There are currently National Control Programmes (NCP's) in place to monitor *Salmonella* in poultry and it is likely that the EU will require similar measures to be applied to *Campylobacter* in the near future. *Campylobacter* research funded by Defra will provide an evidence base on which to inform future policy directions to reduce the prevalence of *Campylobacter* in farm animals and future EU negotiations if such EU-wide control programmes are proposed. This reduction will also contribute to a reduction in incidence of *Campylobacter* infection in humans *via* the food chain.

Defra participates in cross-government research;

4.11 With the FSA, Defra is gathering evidence on the risk of spread of *Campylobacter* and identifying potential abattoir control measures and on-farm biosecurity measures. Such research works towards identifying farm to fork measures to achieve the FSA strategic aim of reducing *Campylobacter* prevalence in UK-produced retail chicken. The Defra Zoonoses Report 2008 provides information on FSA/Defra co-funded *Campylobacter* research projects http://www.defra.gov.uk/foodfarm/farmanimal/diseases/atoz/zoonoses/documents/report-2008.pdf

4.12 BBSRC and Defra share a common interest in basic research, and Defra take this forward into applied settings. Basic research in gut health, *Campylobacter* colonisation mechanisms, the immunology of *Campylobacter* infection and the contribution of genetics, particularly in commercial birds, are key to understanding *Campylobacter* colonisation in animals. These research areas underpin applied research aimed at developing interventions to reduce *Campylobacter* levels on farm. In order to allow basic research to be undertaken Defra and BBSRC co-fund research via the Government Partnership Award (GPA) mechanism.

4.13 Defra funds *Campylobacter* research at UK Universities, Research Institutes and at our main delivery agent, the Veterinary Laboratories Agency (VLA), including collaborative projects with the Health Protection Agency (HPA). Research is also funded outside the UK if appropriate.

FSA

4.14 The Food Standards Agency is an independent Government department set up in 2000 by an Act of Parliament to protect the public's health and consumer interests in relation to food and drink. The FSA is the UK Government department responsible for food safety issues.

4.15 Science is at the heart of the FSA's work. The FSA spends between £25m and £30m each year on commissioned science and evidence, about 17 to 20% of our total resource. The FSA works with other funders to help develop and benefit from the wider base of evidence and expertise, in the UK and internationally. The FSA communicates its science and evidence openly, and has an open-access research repository Foodbase (foodbase.org.uk***/***), so that others can use, and benefit from, its work.

4.16 The FSA Strategy 2010-2015 http://www.food.gov.uk/aboutus/publications/busreps/strategicplan/ includes the outcome that 'Food produced or sold in the UK is safe to eat'. A main priority for this is to reduce food-borne disease using a targeted approach, and tackling *Campylobacter* in chicken as a priority.

4.17 The FSA's vision in relation to *Campylobacter* is to achieve a substantial reduction in the number of human cases of Campylobacteriosis in UK by 2015, to be achieved through a number of measures including a substantial reduction in the prevalence of *Campylobacter* in UK chicken at retail by 2015. We are focussing on the reduction of *Campylobacter* in chicken as studies indicate that 60-80% of cases of Campylobacteriosis can be attributed to chicken[35]. Our Food Chain Analysis project http://www.food.gov.uk/multimedia/pdfs/foodchainhazardsimpacts concluded that the greatest risk of *Campylobacter* infection for people is from poultry meat, and hazards arising along the food chain that can result in the introduction of *Campylobacter* into food.

4.18 The FSA is developing with its stakeholders a *Campylobacter* Risk Management Programme which will encompass a range of projects targeted at different points along the food chain, from farm to fork. To measure progress on the effectiveness of itswork in this area a new target for the reduction in levels of *Campylobacter* in chicken will be set and published by December 2010, to be achieved by April 2015. Although the target will be focussed on the reduction of levels of *Campylobacter* on UK-produced chicken, the ultimate aim is to reduce the number of human infections. Therefore the *Campylobacter* Risk Management Programme will be complemented by other work to improve public awareness and effective use of messages about good food hygiene practice at home and in catering establishments.

4.19 The FSA chairs the Microbiological Safety of Food Funders Group (MSFFG), see para 1.22. Further details on the MSFFG and its membership can be found at www.food.gov.uk/science/research/foodborneillness/microfunders/msffg/

[35] Sheppard, S. K., Dallas, J. F., Strachan, N. J. C., MacRae, M., McCarthy, N. D., Wilson, D. J., Gormley, F. J., Falush, D., Ogden, I. D., Maiden, M. C. J. and K. J. Forbes (2009) *Clinical Infectious Diseases* **48**: 1072-1078

Department of Agriculture and Rural Development for Northern Ireland

4.20 DARD's vision is to create and maintain a thriving and sustainable rural community and environment in Northern Ireland. This mission is underpinned by four strategic objectives: to improve performance in the market place; to strengthen the social and economic infrastructure of rural areas by working to create a strong rural community with more businesses and jobs than before; to improve animal, fish and plant health and welfare by working towards a reduction in diseases; and to develop a more sustainable environment.

4.21 DARD sponsors a comprehensive research programme across the agri-food sector in Northern Ireland to provide a sound, scientific basis for government policy on agriculture and the environment and to underpin development in the agri-food private sector. Research is largely commissioned through the Agri Food and Biosciences Institute (AFBI).

4.22 DARD research funding is primarily concentrated on applied and experimental development research activities. The research programme includes work on: food industry sustainability, (quality and consumer choice, novel processes and products), consumer confidence, (food safety and traceability); sustainable food and farming including sustainable forage and crop systems, sustainable and competitive livestock systems (dairy, beef, sheep, pigs and poultry systems); and animal health, management and protection of natural resources and agriculture and food economics.

4.23 One of DARD's strategic objectives is to enhance animal health and welfare, fish and plant health. Faster, more accurate and less costly detection of such diseases will ultimately assist in disease eradication programmes and the early detection and prevention of the spread of new diseases.

Key interactions with other funders:

4.24 DARD is closely involved in joint funding with Defra, other devolved administrations and Northern Ireland levy bodies such as AgriSearch. Funding of research is also discussed with a wide range of local stakeholder groups.

Scottish Government

Economic Strategy

4.25 The purpose of the Scottish Government is to create a more successful country with opportunities for all of Scotland to flourish, through increasing sustainable economic growth. The Government's Economic Strategy (November 2007) sets out five strategic objectives towards which all policies and resources are focussed and through which sustainable economic growth will be delivered: *Wealthier and Fairer*, *Healthier*, *Safer and Stronger*, *Smarter*, and *Greener*.

http://www.scotland.gov.uk/Publications/2007/11/12115041/0

Co-ordinated Agenda for Marine, Environment and Rural Affairs Science (CAMERAS)

4.26 CAMERAS has been set up to ensure that all science supported in the Rural Affairs and Environment (RAE) portfolio is effectively targeted in support of the *Greener* and *Wealthier* objectives of the Scottish Government and the primary purpose of sustainable economic growth. This partnership includes key Policy Directorates in the Scottish Government (the main customers of the research) and nine partners who commission research.

http://www.scotland.gov.uk/Topics/Research/About/EBAR/CAMERASsite

4.27 Partnership working also features at UK level, with the major funders of food and environmental research (e.g. Research Councils and Government Departments) having made commitments to align their strategies through co-ordinated programmes of research with as strong focus on impact. The two co-ordinated programmes of relevance to RAE research are: '**Living with Environmental Change**' http://www.lwec.org.uk/ and the **Global Food Security** programme www.foodsecurity.ac.uk

Wellcome Trust

4.28 The Wellcome Trust is a global charity dedicated to achieving extraordinary improvements in human and animal health. The Trust supports the brightest minds in biomedical research and the medical humanities. The breadth of its support includes public engagement, education and the application of research to improve health. The Trust is independent of both political and commercial interests. It has provided significant support to *Campylobacter* research through e.g. genome sequence and microarray research.[36]

4.29 Annual grant commitments (£k) towards *Campylobacter* and food-borne zoonoses (FBZ):

Financial Year	2005/06	2006/07	2007/08	2008/09
Campylobacter	8	2,059	140	491
FBZ	2,520	4,544	2,809	5,865

4.30 This table is based on a 'key word' search of active grants, and represents annual grant commitments in each area. In addition to those grants directly identified as FBZ, this category also includes grant commitments relating to *Salmonella, Shigella* and *E. coli.*

[36] http://www.msffg.org.uk/reports/reports/*Campylobacter*3.pdf

5 Relevant reports

5.1 Several reviews of UK research programmes have been completed over the last few years. These include:

MSFFG reports on *Campylobacter* research

- http://www.msffg.org.uk/reports/reports/*Campylobacter*1.pdf
- http://www.msffg.org.uk/reports/reports/*Campylobacter*2.pdf
- http://www.msffg.org.uk/reports/reports/*Campylobacter*3.pdf

5.2 Other relevant reviews include:

- FDA Produce safety project http://www.producesafetyproject.org/media?id=0009

ACMSF reports on *Campylobacter*

- Interim Report on *Campylobacter* , 1993
  http://www.food.gov.uk/multimedia/pdfs/acmsfinterimcampylob.pdf
- Second Report on *Campylobacter*, 2005
  http://www.food.gov.uk/multimedia/pdfs/acmsfcampylobacter.pdf
- Report on Poultry Meat (1996)
  http://acmsf.food.gov.uk/acmsfreps/acmsfreports

EFSA Scientific Opinions and reports

- Opinion of the Scientific Panel on biological hazards (BIOHAZ) related to *Campylobacter* in animals and foodstuffs, adopted January 2005
  www.efsa.europa.eu/en/scdocs/scdoc/173.htm
- The Community Summary Report on trends and sources of zoonoses, zoonotic agents and food-borne outbreaks in the European Union in 2008
  http://www.efsa.europa.eu/en/scdocs/scdoc/1496.htm
- Scientific Opinion on Quantification of the risk posed by broiler meat to human Campylobacteriosis in the EU, adopted December 2009
  www.efsa.europa.eu/en/scdocs/scdoc/1437.htm
- EFSA report: "12th EFSA Scientific colloquium Summary report: Assessing health benefits of controlling *Campylobacter* in the food chain" 4-5 December 2008, Rome, Italy" http://www.efsa.europa.eu/en/events/event/colloque081204.htm

6 Background to the priorities

6.1 The priorities in this strategy have been identified as important to the delivery of future reduction of *Campylobacter* levels in the UK food supply chain, and were developed from a wider set of priorities identified by academics, industry and policymakers at a joint funders' strategy workshop in October 2009. Delegates at the workshop were asked to identify potential research priorities, which were merged and distilled to a single list (below). Delegates were then asked to rate the relative importance of these. The priorities in this strategy are the highest ranked priorities from the list.

6.2 Priorities were verified against other recent reviews and an international workshop held by FSA in March 2010.

T**he full list is in no particular order of priority**

- Genetic diversity and phenotypic variation, a strain bank?
- Need for *Campylobacter* studies in host organisms and the balance between strains and types
- Microbiota of the chicken gut, effect of welfare, feed, other factors e.g. gut triggers
- How does chicken's diet, age and growth rate affect the emergence of *Campy*
- Understanding colonisation of the chicken
- Seasonality?
- Understanding all aspects of the age of chickens on *Campylobacter* status
- Developing genetically resistant strains (of chicken)
- Immune response of chickens
- Welfare and stress - thinning, lighting, stocking density
- Vaccines
- Bacteriophage, bacteriocins and other new anti-microbials
- Feed, feed regime, pre/probiotics, organic acids etc
- Trialling of interventions: large scale, on-farm
- Compare real life systems
- On-farm management and biosecurity and production systems
- Transportation/ slaughter house studies
- On farm transmission factors and within flock transmission dynamics

- Need for efficacy data on what interventions actually work
- Human behaviour in production processes and on farm and human transmission, e.g. packaging
- Practice in the kitchen, preparation and cooking practices
- Consumer/retailer attitudes to interventions
- Complexity of the human interaction with the organism and complexities of human immunity
- Need for a rapid test for *Campylobacter*
- Model farms or access to other large scale facilities
- Small animal model for human disease
- The facts of other interventions in Europe
- Survival in the environment(s)
- Base line surveys linked to efficiency of intervention
- Modelling the whole chain, bird to human
- Importance of non-chicken sources

7 Abbreviations

ACMSF	Advisory Committee on the Microbiological Safety of Food
APEC	avian pathogenic *Escherichia coli*
BBSRC	Biotechnology and Biological Sciences Research Council
BIOHAZ	EFSA Scientific Panel on biological hazards
BPC	British Poultry Council
DARD	Department of Agriculture and Rural Development in Northern Ireland
Defra	Department for Environment, Food and Rural Affairs
DH	Department of Health
E. coli	*Escherichia coli*
EFSA	European Food Safety Authority
FBZ	food-borne zoonoses
FSA	Food Standards Agency
MRC	Medical Research Council
MSFFG	Microbiological Safety of Food Funders Group
QTL	Quantitative Trait Loci
RAE	Rural Affairs and Environment
SNP	Single-nucleotide polymorphism