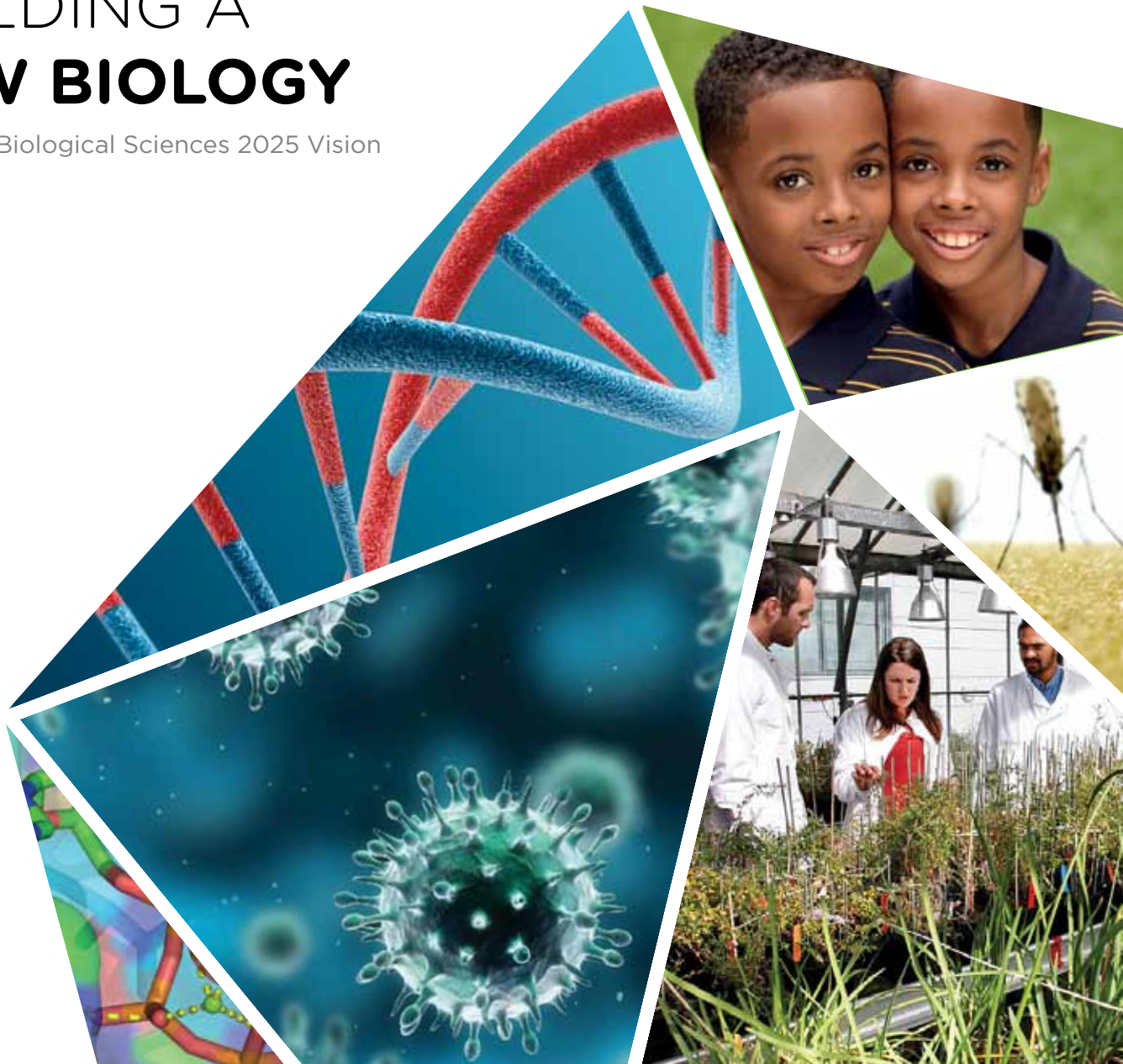
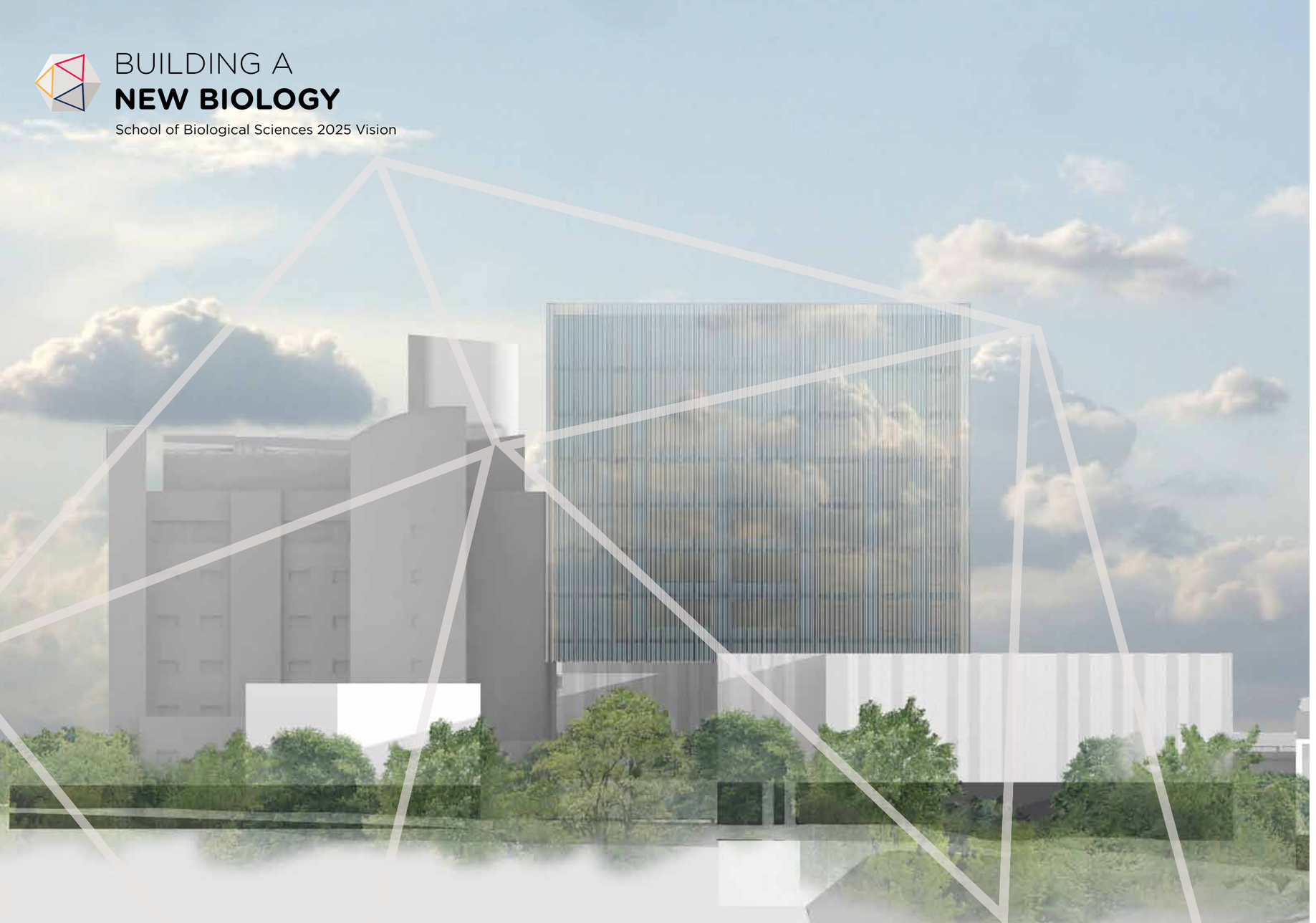
THE UNIVERSITY *of* EDINBURGH
School of Biological Sciences

# BUILDING A **NEW BIOLOGY**

School of Biological Sciences 2025 Vision





# BUILDING A **NEW BIOLOGY**

School of Biological Sciences 2025 Vision

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**www.ed.ac.uk/schools-departments/biology**

# Foreword

We are poised to deliver the next revolution in biology. Today, biology is no longer simply about interrogation and analysis; the advent of advanced synthetic biology methods means we can now learn by building. The School of Biological Sciences is commencing an ambitious strategic plan to 'Build a New Biology' that includes growth in the numbers of researchers and students and the re-development of our estate and infrastructure. This will not only deliver a more secure and sustainable future for both our research community and our students but also allow us to build further on our leading position in the UK and internationally.

Over the next five years, we will create a powerhouse of research and innovation on the King's Buildings campus in Edinburgh. To lead in today's competitive international environment, and to realise the substantial opportunities offered by our world-class research community, we need world-class laboratories to match.

We have embarked on an estate re-development project that will see enhanced integration of our research activities, nurturing the cross disciplinary collaborations. Some of the exceptional research that will arise from novel co-locations in our new buildings can be foreseen, for instance just by browsing the pages here. Truly transformational science is hard to predict today but will be made possible tomorrow by the structures we are putting in place now.

Our ambitious plans are made possible by the imaginative and forward-looking support of the University of Edinburgh. We are also building productive partnerships with industry, charities and public sector bodies to enhance the impact of our research and teaching in the Scotland, the UK and globally. Engagement with our community is critical to realising this vision and this is an important component in the project delivery.

New buildings require new investment and we are planning a substantial fundraising campaign to realise our 2025 vision for the School. Here we want to share with you our aims and our strategy for growth and hope that you will support us and follow us on our journey.

***Head of School, Professor David Gray, FSB, FRSE***

# Executive summary

The School of Biological Sciences at the University of Edinburgh is a leading centre for research and teaching with an enviable global reach and reputation. For centuries we have generated insights and innovations that have benefited the health and wealth of our world. Over the coming decade, we intend to build on this reputation and are planning an ambitious expansion that will make us a powerhouse of biological research and innovation in the UK.

Modern technology has revolutionised research in the life sciences: biology is no longer simply about analysis and interrogation, but also about learning through building. As a School we too must construct a secure and sustainable future for both our research community and our students. The cornerstone of our plans for growth is developing our estates and infrastructure with a >£100 million investment over the next five years to create an exciting 'New Biology' complex on the King's Buildings campus in Edinburgh. This will provide a physical and metaphorical heart for all our research, teaching and engagement activities.

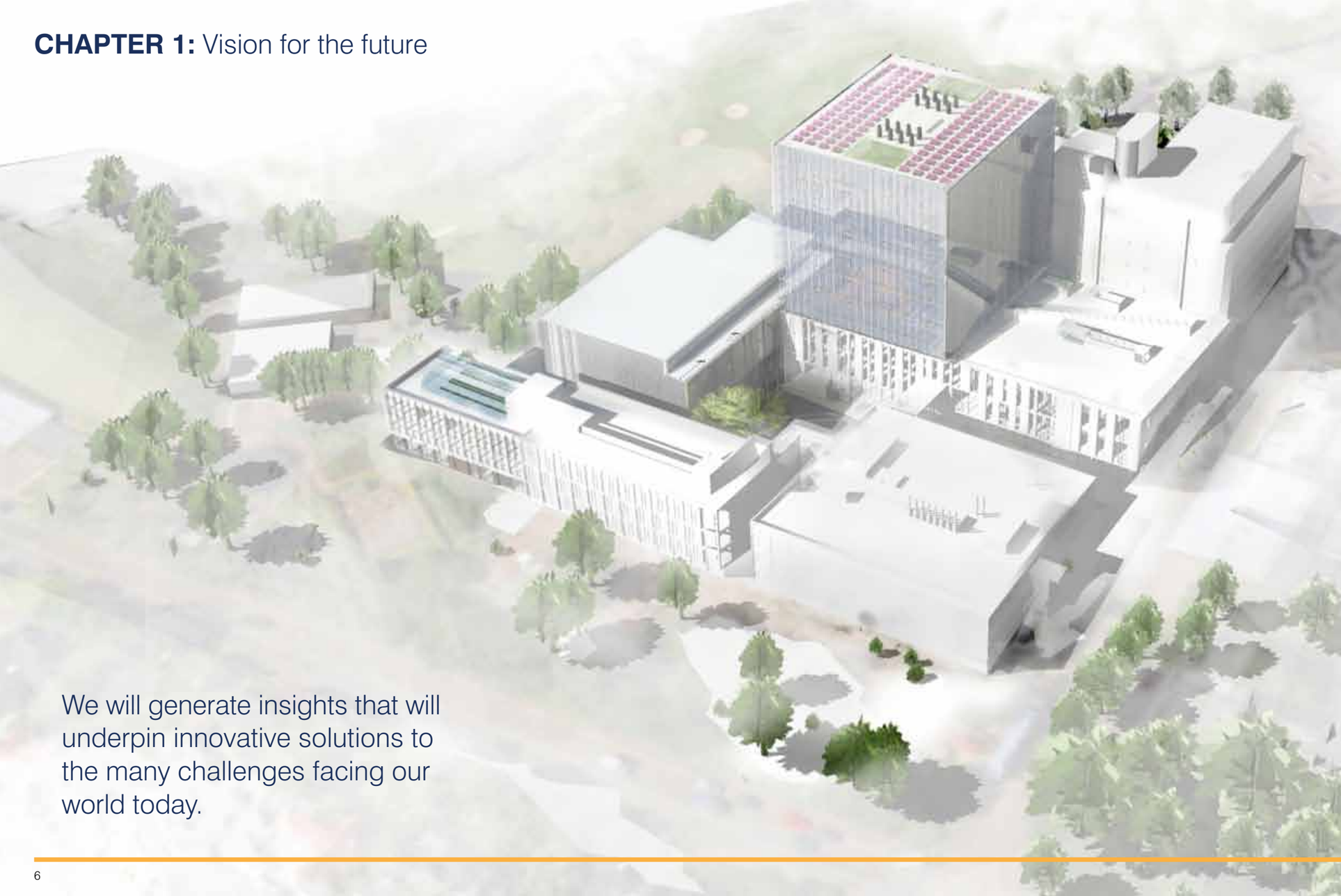
We will build new and exciting research programmes around three key research areas: Epigenetics; Infection and Global Health; and Synthetic Biology. This will require investing in our people and also in developing an ethos of creative collaboration. Only by nurturing interdisciplinary collaborations can we deliver truly world-beating science and address the many challenges facing our planet today.

**Our goals**

We have an ambitious long-term vision for our School and by 2025 we aim to:

- Create an integrated environment for cross-disciplinary collaborations that push the boundaries of knowledge;
- Increase our research volume by 50%;
- Double the economic and social impact of our activities;
- Increase by 50% the number of postgraduate students that we train;
- Deliver innovative approaches to teaching to meet the demands of biology for the 21st Century.

# **CHAPTER 1:** Vision for the future



We will generate insights that will underpin innovative solutions to the many challenges facing our world today.

The School of Biological Sciences has been delivering ground-breaking research and teaching in the life sciences for decades. We have revealed the operation of complex biological molecules and pathways, the processes that control the function of living cells, and the systems that determine how organisms and populations co-exist, inherit and evolve.

We are standing on the edge of a biological revolution. We can rapidly read the entire human genome; we can analyse how genes and proteins differ in health and disease; we can predict how complex systems make decisions; and we can design methods to interrogate and model the vast data sets generated through all these capabilities. But today biology is no longer simply about measuring, dissecting and probing: we can design and construct biology *de novo* – we can learn through building.

Our vision is to create a fully integrated, world-leading research environment invigorated by the momentum of this biological revolution. We will focus on three research themes that address intellectually challenging areas of biology and promise long-lasting benefits for our world: **Epigenetics**; **Infection and Global Health**; and **Synthetic Biology**.

We will generate insights that will underpin innovative solutions to the many challenges facing our world today: human diseases and disabilities, especially those associated with ageing; the fight against infection globally, including emerging pathogens and spread of antimicrobial resistance; the need for more sustainable means of producing medicines, food, materials and fuel to satisfy the needs of the growing number of consumers globally.

# 1:1 Our School

Our School is one of the world's leading hubs for biological research and education. We have an outstanding reach and reputation that consistently ranks us in the top UK and global unviversities.[1] Since the first recorded study of biological sciences in Edinburgh in 1695, we have written a rich history of excellence in biology, reflected in the diversity and quality of our research and our teaching and its benefits to society. Here we explore the diversity of our activities and their many impacts to provide context for our ambitious plans for the future.

## Highlights

- Over 90% of our research was ranked internationally excellent in the latest independent Research Excellence Framework assessment (REF2014).[2] Overall, we were ranked third in the UK for world-leading research quality and third for world-class research impact.
- We secure >£30 million per annum of research grants and funding from Government, charitable, industry and other sources. In the past five years this amounts to £154 million dedicated to research.
- We were awarded an ATHENA SWAN Silver Award in 2013 to recognise our commitment to equality and diversity in the workplace. More than one in four of our professors is female, higher than the UK average.
- We are home to eight Fellows of the Royal Society. Recently Professor Adrian Bird was awarded a Knighthood for his services to science.
- We attract the highest quality students and our graduate employability is amongst the best in the world.

**1583**
Founding of the University of Edinburgh

**1695**
First Chair of Botany created

**1772**
Daniel Rutherford, appointed to the Chair of Botany at Edinburgh, discovers Nitrogen

**1795**
Robert Brown, discoverer of 'Brownian Motion', studies botany at Edinburgh

**1825**
Charles Darwin studies medicine, biology, zoology and geology at Edinburgh

**1913**
Botanist, Bertha Chandler is the first woman to be awarded a Doctorate by the University of Edinburgh

**1929**
The first purpose built biology labs, The Ashworth Laboratories, are constructed on the King's Buildings campus

**1940s**
Charlotte Auerbach demonstrates the mutagenic effects of chemicals on living organisms

**1946**
Conrad H Waddington, founder of 'epigenetics', appointed to the Buchanan Chair of Genetics

**1970s**
Max Birnstiel isolates a single vertebrate gene for the first time

The 'Southern blot', universally used to identify specific DNA fragments, is invented by Ed Southern

Jean Beggs pioneers the technique of cloning in yeast

Peter Mitchell is awarded a Nobel Prize for Chemistry for his research on ATP synthesis

**1980s**
Ken Murray's work leads to the development of the first Hepatitis B vaccine

**1980s and 1990s**
Malaria research provides great advances in our understanding of the genetics and transmission of the disease

**2003**
Ian Chambers and Austin Smith discover the Nanog gene, a key determinant of pluripotency in embryonic stem cells

**2005**
Rick Maizels' work demonstrates a causal link between parasite infection and suppression of allergic symptoms

**2007**
Adrian Bird's research provides new hope for reversal of neurological diseases such as Rett syndrome

**2009**
Andrew Rambaut helps inform the global response to the H1N1 influenza pandemic by mapping the evolution of viral infection

**2011**
Andrew Millar and collaborators discover the first biological rhythm that is shared across all domains of life

**2012**
Loeske Kruuk and colleagues show that climate change is detrimental to fitness in a wild mammal

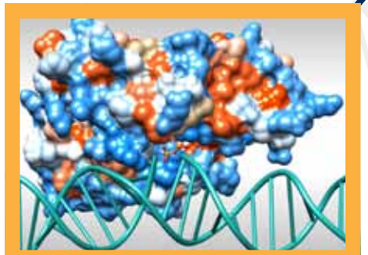
**2014**
Patrick Cai and international collaborators build the first artificial eukaryote chromosome

Clare Blackburn and Nicholas Bredenkamp create the first fully-functional experimental organ from reprogrammed cells

# 1:2 World-class research

We are among the largest clusters of biological researchers in the UK providing a supportive environment to 135 Principal Investigators and 500 additional staff working as researchers, technical specialists or in professional services. We believe in collaboration and cooperation, working closely with the physical sciences and medical and veterinary researchers across the University campuses and beyond. Our research is exceptional in its depth and breadth across scale (from molecular to population), time (from the nanosecond to evolutionary timescales) and organism (plants, animals, microbes).

## Genes, Proteins and Cells



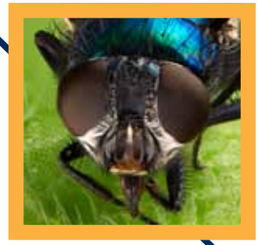
We explore the structure, function, stability and development of genes, proteins, and cells (including stem cells) in microbes, plants and animals. This offers insight into processes underpinning health, ageing and disease, in turn enabling the development of new diagnostics and medicines and benefits for agriculture.

## Networks and Systems

We have world-class expertise in systems biology, which integrates biological and physical data using sophisticated mathematical algorithms to create models of biological processes, systems and even entire organisms. This allows us to predict how living systems respond to change, how we can manipulate these systems or potentially design new ones. Our expertise in synthetic biology will allow us to further manipulate systems to consolidate and expand our understanding of the complexity of natural systems.

Our research is exceptional in its depth and breadth.

## Organisms



We work with a variety of model systems both in the laboratory and in the field: yeast, bacteria, viruses, parasitic worms, mice and larger mammals, model plants and field crops, insects and birds. These models are of value for understanding the processes of development and disease in plants, animals and humans.

## Populations

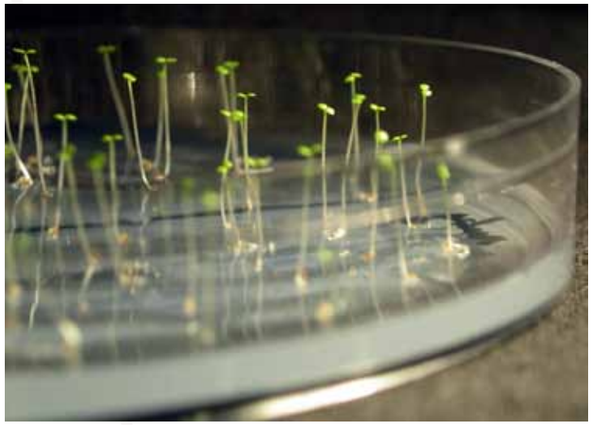
We have expertise in ecology and epidemiology and are home to one of the largest groups of evolutionary biologists in the world. We explore how populations of organisms interact with their environment and the mechanisms underlying inheritance and evolution.

## Chemical communication translated

Bacteria recognise their physical and social environment by producing, and responding to, chemical signals. Dr Sam Brown's team found that bacteria respond differently to a combination of two chemical signals than to either alone. Until recently, only humans and other primates were thought to engage in what is called combinatorial communication, where a signal can have different meanings depending on its context. Many antibiotics work by blocking all bacterial 'chatter', but this can lead to the survival of drug-resistant strains (e.g. MRSA). More subtle interventions, such as blocking only those bacterial chemical signals that make us sick, might clear infection without leading to antibiotic resistance.

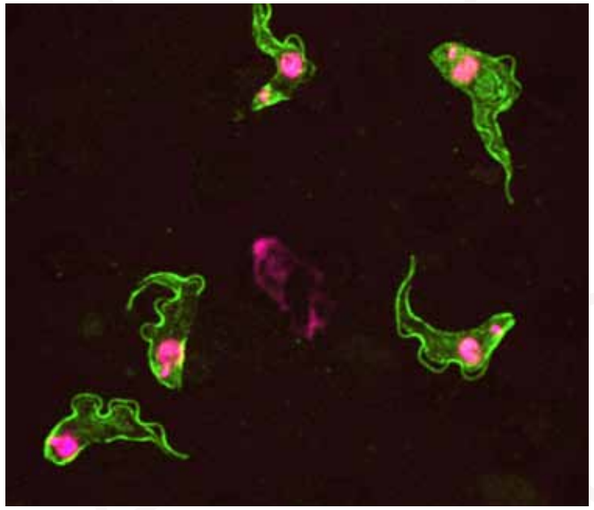
## Virtual plant models future crops

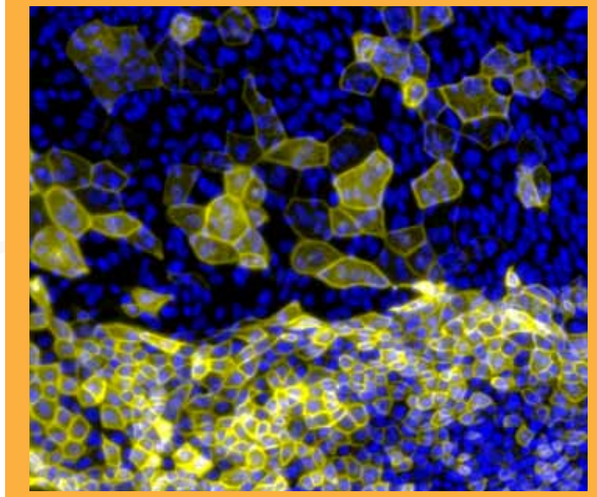
Exploration of the biological systems that underpin the growth of plants could have far-reaching implications for the plant breeders of the future. Professor Andrew Millar and his international collaborators built a computer model that explores how plants are influenced by varying conditions of light intensity, day length, temperature and carbon dioxide. They then tested, and validated, this model in the lab using small cress plants. The model accurately predicted that plant varieties differ in the way they distribute nutrients depending on the conditions: some develop leaves and fruit that are smaller, but more abundant, than other varieties. This model offers a valuable insight into how plants could adapt to ensure survival in less favourable conditions and may equip the plant breeders of the future with the tools to create more 'climate-resistant' crop varieties.



## Fighting sleeping sickness

The School was awarded £2.5 million from the Welcome Trust, the UK's leading medical charity, to develop a new drug against Human African Trypanomiasis (sleeping sickness). Professor Malcolm Walkinshaw led a team that found they could kill the parasite by blocking an enzyme that converts glucose into ATP (a universal form of energy). Professor Walkinshaw has screened an extensive chemical library in the USA and found several with the ability to block this enzyme. He is now modifying them to be better suited for use as drugs in humans with international life sciences company, Selcia.





## Edinburgh first in regenerative medicine

Professor Clare Blackburn and colleagues have grown a fully functional organ from transplanted laboratory-created cells in a living animal for the first time. They took fibroblasts (skin cells) from a mouse embryo and reprogrammed them into thymus cells. The reprogrammed skin cells not only changed shape to look like thymus cells but also supported development of T (immune) cells in the lab – a function that only thymus cells can perform. When transplanted into a mouse, these same cells can form a new organ with the same structure, complexity and function as a healthy adult thymus. With further refinement, these cells could be used to help boost weakened immune systems to treat a variety of diseases.

# 1:3 Inspirational teaching

We play a key role in teaching and training the next generation of biologists, whether they pursue careers within academia, industry or one of the many alternative career paths open to those with a solid grounding in modern biology.

Our Biology Teaching Organisation administers the undergraduate and taught postgraduate (Masters) teaching programmes for over 2,000 students. Our students are offered a wide choice of programmes and access to training in transferable skills that equip them for success in their future careers.

Our PhD students pursue research projects in collaboration with industry and with other research organisations both in the United Kingdom and abroad. Their research leads to publications in eminent scientific journals and many have received external recognition for their creativity and excellent communication skills.

The School also participates in Innovative Learning Week when normal teaching is suspended and replaced by a series of creative and experiential learning events for staff, students and the public.

### Fostering excellence

Postgraduate student Emma Hodcroft, working in the laboratory of Professor Andrew Leigh Brown was a finalist in the UK University 3 Minute Thesis Competition. Three Minute Thesis (3MT) is a research communication competition developed by The University of Queensland in Australia that challenges postgraduate students to present their thesis and its significance in just three minutes in language appropriate to a non-specialist audience. Emma went on to participate in the international 3MT competition.

# 1:4 Creative communication

Communication and dissemination is a fundamental part of scientific endeavour and its progress, and we are keen to share our passion for our work. We open our doors not only to potential students but also their friends and family, to our neighbours in Edinburgh and to the wider public. Our staff and students participate in high-profile and lively science and cultural festivals such as the Edinburgh Science Festival, Midlothian Science Festival and Edinburgh Open Doors, using creative ways to explain what we do, why and its benefits.

We work with teachers to take science to schools, providing exciting hands-on experience of what science is really about to pupils of all ages. We have also developed and run fun and informative outreach activities at events around the country.

We use social media, films and podcasts to explain our research. Our outreach activities have won external recognition for the substantial impact they have made on the public's understanding of science.

### The story of stem cells

The University has made a substantial contribution to the public debate on stem cells. Professor Clare Blackburn led the programme funded by a major European grant (EuroStemCell) to establish the website www.eurostemcell.org and develop films and educational materials that explore the fascinating science of stem cells. The website has had over a million visitors and is a major portal for trusted, accurate and up-to-date information on stem cells and regenerative medicine written in plain English (and translated into six European languages). The content is followed by the media, educators and patients alike and used to inform politicians. Downloads include a toolkit of different stem cell outreach activities, and a graphic short story 'Hope Beyond Hype' that explores the process by which a scientific discovery becomes a new therapy. The team also produced four short documentary films about our stem cell research, a feature-length documentary 'Stem Cell Revolutions: Vision of the Future' and a short educational film. The films have won multiple awards and have thousands of viewings via YouTube and via DVDs for schools and patients.

# 1:5 Pioneering innovation

Much of our research is fundamental in nature, yet the discoveries and insights generated can be translated into products and services of value for agriculture, healthcare, food and drink, materials, the environment and energy, and other emerging industry sectors.

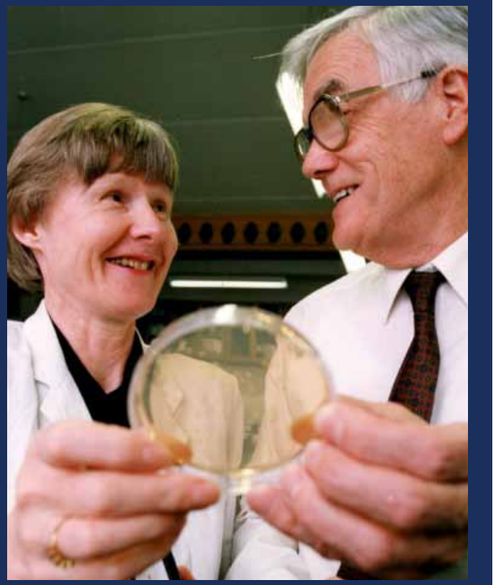
The road from making a fundamental biological insight to delivering a new product or process is long and often costly; indeed, not all good ideas can be turned into commercially viable propositions. Nevertheless, our research has made a significant contribution to the creation of many valuable products and services. Indeed, our School was home to one of the very first pioneers in the biotechnology industry, Professor Sir Ken Murray, whose research underpinned the development of the first genetically-engineered vaccine against Hepatitis B.

## Highlights

- Between 2008 and 2013 our researchers made 92 inventions, filed 10 patent families and signed 50 license agreements;
- We have received £5 million from industry in support for research and funding for students since 2008;
- The licensing of our intellectual property has generated ~£2 million in income over the past decade, which has funded new research;
- We carry out around 20 consultancy contracts each year for a variety of customers;
- Our reputation attracts the interest of industry globally and over the past two years more than 40 companies have visited the School.

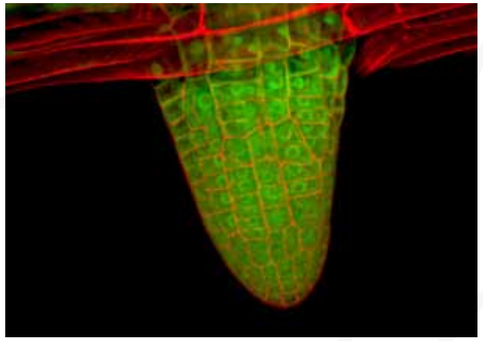
### A PIONEER IN BIOTECHNOLOGY

Perhaps the School's most celebrated entrepreneur is Professor Ken Murray, who helped develop the first genetically-engineered vaccine against the Hepatitis B virus. Ken Murray, along with his research collaborator and wife Professor Noreen Murray, worked in Edinburgh to pioneer the then novel technique of genetic engineering that underpins modern biotechnology. The Hepatitis vaccine and diagnostic kit that Professor Murray created was developed commercially by Biogen, which he founded in 1978 with several other distinguished biologists. Today Biogen Idec is one of the world's oldest biotechnology companies and the vaccine developed at Edinburgh has saved millions of lives. Royalties from sale of the vaccine helped establish the Darwin Trust of Edinburgh, a charity which continues to support undergraduate and postgraduate students of biology (400 to date) and other scientific endeavours. Professor Murray, who died in 2013, was knighted in 1993 for services to science.



### Genetic boost for milk production

Fundamental genetic research in the School led by Professor Bill Hill and Dr Sue Brotherstone formed the underpinning science for production models for the dairy industry. As a result, UK dairy farmers can now select the best animals for breeding, leading to improved productivity, greater efficiency and reduced environmental impact. Independent analysis suggests that the dairy industry has benefited by an additional £440 million in revenue between 2008 and 2013 as a result of this innovation.[3]



### Plant stem cells offer a natural solution

Professor Gary Loake and colleagues developed a range of specialist techniques for characterising unique plant (stem) cells that can be used as 'green factories' for natural products used in medicines, cosmetic ingredients and food additives. The technology was licensed to a Korean biotech company, Unhwa Corporation, and has enabled them to triple the production of these plant stem cells and bring new products that are now are sold worldwide and have helped double company turnover.

# 1:6 Economic benefits

We asked experts to quantify the value of our activities within the local (Edinburgh), Scottish and UK economy.[4] This was carried out using two standard measures: Gross Value Added (GVA), which provides a measure of the monetary contribution of the organisation to the economy; and employment, measured in full-time jobs created and supported. These metrics comprise several elements: the direct impact of operations (salaries, purchases, spending of staff and their visitors); the additional economic value of graduate training; and the financial value generated by translation of our research outputs into products and services.

Although just a snapshot in time, the analysis provides a useful benchmark for the projected impact of our investment plans. The total economic benefit of the School's activity to the UK was £160 million GVA and 2,200 jobs: for every £1 of research funding the School generates £4.50 in benefits for the UK.

Our activities already make a significant contribution to the economy of the UK and Scotland, as well as to the city of Edinburgh. By investing in growth, we wish to double this contribution over the coming decade.

**THE ECONOMIC VALUE (PER ANNUM) OF THE SCHOOL'S ACTIVITIES**

| JOBS | GROSS VALUE ADDED |
|---|---|
| 2202 UNITED KINGDOM | £160 million UNITED KINGDOM |
| 1562 SCOTLAND | £80 million SCOTLAND |
| 1042 EDINBURGH | £49 million EDINBURGH |

## Malaria diagnostic supports safe blood supply and creates economic value

Around 60,000 blood donations in England were being discarded annually because donors had been exposed to the risk of malaria. The problem was escalating as more people travelled to, and emigrated from, endemic areas. Diagnostic developer Lab21 collaborated with Drs Jana McBride and David Cavanagh to develop a malarial antibody detection test (Enzyme ImmunoAssay). This is now used to screen blood donations across the UK. The malaria test allows early re-admittance of perceived malarial 'at-risk' donors to blood donation programmes and helps to secure life-saving blood for treating patients. Over 700,000 assays are now performed per year and more than 345,000 blood donations from malaria-risk donors have been cleared for clinical use. As well as the benefit to patients, the sale of almost 2.5 million test kits has generated over £1.45 million in commercial value for the production companies and a significant saving for national healthcare budgets (>£30 million each year between 2008 and 2013).[4]


# 1:7 Global impact

Our global impact arises from development of new drugs and therapies and from commercialisation of our discoveries to create new products and new industries. Much of our work has benefits that may be hard to quantify in economic terms but are no less profound for society, with impacts both locally and globally. The knowledge we generate through research provides the ideas and evidence that influence and inform public policy, impacting on health, welfare and the environment, and through contributing to public awareness and practice in areas such as farming, medicine and conservation. We also create value by training the next generation of scientists, who will go on to become entrepreneurs, industry leaders, teachers, medical professionals, policy makers and to contribute in many other walks of life in the UK and internationally.

**INNOVATIVE AND FUNDAMENTAL BIOLOGICAL INSIGHTS**

***Routes to impact***

- Teaching and Training
- Knowledge Exchange and Commercialisation
- Operational Impacts
- Policy and Public Engagement

***Benefits to Society***

**Health and Wellbeing**

- Innovative diagnostics and medicines for humans and animals
- Infection control
- Public health policy


**Environment**

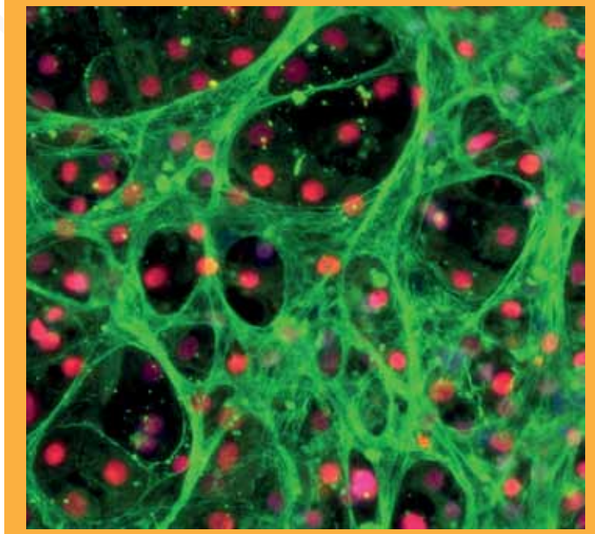
- Resilience to climate change
- Sustainable food, fuel and materials
- Reducing waste
- Environmental policy

**Economy**

- New, greener industries
- Highly skilled workforce
- Boosting UK competitiveness
- Effective public policy

## Promoting native woodlands

The work of Professor Richard Ennos and collaborators embedded the use of well-adapted sources of forest tree seed in native woodland planting policy across the UK. They showed that native woodland derived from locally adapted stock becomes both better established and more resilient to native and introduced diseases than non-adapted seed. Today, tree planting grants will only be paid if appropriately adapted seed is used. This policy has had a significant impact on industry: 67% of native woodland seed is now locally sourced, representing £4 million of the £8.2 million trade in British native trees.[5]



## Fundamental stem cell discoveries drive new market opportunity

Stem cells are cells that either self-renew or differentiate into different cell types at each cell division. Embryonic stem cells are stem cells which are pluripotent: they can differentiate into almost any type of cell. Research by Professor Austin Smith and colleagues into the factors governing the self-renewal and pluripotency of embryonic stem cells led to new techniques for selecting undifferentiated mammalian stem cells and also for growing these cells in culture. This work has not only had a profound impact on fundamental scientific and medical research into stem cell therapies and regenerative medicine, but also generated economic impact through a range of commercially-marketed products for culturing stem cells developed by US company, StemCells Inc.

## Prevention better than cure

After malaria, Schistosomiasis (bilharzia) is the second most important parasitic infection of public health concern in Africa. Larvae of the schistosomiasis parasite are released from freshwater snails and penetrate skin in contact with infected water. Symptoms are caused not by the worms themselves but by the individual's immune response to the worms' eggs. Children suffer the most: untreated infections acquired in childhood can lead to kidney and bladder disease, bladder cancer, reduced fertility and susceptibility to HIV infection. Research led by Dr Francisca Mutapi challenged previous assumptions that treatment of pre-school children with the anti-parasitic drug Praziquantel (PZQ) was ineffective. Her work has radically shifted public health policy and the World Health Organisation now recommends that children under 6 years of age, who had previously been excluded from drug treatment, should be treated. This amounts to ~10 million children in affected countries. Around 350,000 pre-school children in Zimbabwe have so far been treated with PZQ and 1.2 million more will be included in the next round of mass drug administration by the Ministry of Health.

## Welfare of hens improved by battery cage ban

Research carried out by Dr Mike Appleby and colleagues on the relationship between cage design and the welfare of laying hens contributed to an EU-wide ban on the use of small, barren battery cages in egg production. The conventional battery cages used to house laying hens resulted in many health and welfare issues. Our research showed that it was possible to minimise the main disadvantages of cages whilst keeping the advantages, especially of economy, by designing a 'furnished cage' for birds which encouraged normal laying behaviour, better wellbeing and increased productivity. Ultimately this work informed the 1999 EU Directive and the 2012 ban on conventional battery cages for laying hens. In 2012, around 48% of UK laid eggs came from furnished cages compared with just 9% in 2009 (DEFRA figures). The ban impacts on more than 1.3 billion laying hens in Europe and in New Zealand where a similar directive was implemented. Without research into the furnished cage, it is likely that the ban would not have been passed into law as it would have rendered the EU egg industry internationally uncompetitive.

## Now is the time to build on our success.

We plan to create an even stronger powerhouse of biological research here in Edinburgh. Our ambition is invigorated by the momentum of the changing face of biology and the power of emerging technologies, and driven by the need to address ever more pressing global challenges.

We have chosen three research themes on which to build: **Epigenetics**; **Infection and Global Health**; and **Synthetic Biology**. These address intellectually challenging areas of biology and promise long-lasting impacts for our world.

# 2.1 Epigenetics

Conrad H Waddington, then the Buchanan Professor of Genetics at the University of Edinburgh, coined the term ‘epigenetics’ in 1942 to refer to the study of how genetic information is ‘read’ during development of the embryo to give rise to a whole organism. Today, we know that our genome is decorated with chemical labels in complex patterns, which influence how the information encoded in genes is expressed. Failure to read, copy, maintain or erase these chemical labels – so-called epigenetic marks – can lead to devastating disease. Proteins that read, write or erase these epigenetic markers are now implicated in many human diseases and are targets for drug discovery.

**What’s the challenge?** To understand how the information encoded in the genome is managed to maintain health and how defects in this ‘epigenetic’ management system cause disease. Our research will impact on understanding of ageing, cancer, neurological disorders and many other conditions.

**What’s our aim?** First, we seek to understand the fundamental principles of epigenetic control of genes during a cell’s life, how this is inherited and passed to offspring. Second, we aim to identify what happens when epigenetic processes fail.

We can test these hypotheses by using synthetic biology techniques to build and edit genomes and chromosomes. We can develop novel cellular assays better suited for our search for new epigenetic drugs. Uncovering the secrets of the epigenome will enable us to find previously unsuspected ways to alleviate disease over the next decade.

With world-leading expertise in cell biology in the Wellcome Trust Centre for Cell Biology, we have an ideal base from which to generate new understanding of epigenetics in health and disease of both plants and animals across their life course.

## New hope for Rett syndrome

Rett syndrome is a neurological disorder that affects 1 in 10,000 girls. It starts in childhood and leads to a progressive loss of speech and hand movement, coupled with autistic behaviour, brain and growth retardation. In most cases the disease is due to mutations in the gene coding for a protein (MeCP2) involved in DNA methylation and epigenetic modifications.

For many years, Rett syndrome was believed to be incurable. This all changed in 2007 when Professor Sir Adrian Bird, the current Buchanan Professor of Genetics, and his team published a landmark paper showing that the disease could in principle be reversed (from studies they had carried out in mouse models) even in late stages. For the first time the focus was switched from simply managing symptoms to actually finding a cure.

This discovery radically changed perception about neurological diseases and has stimulated the creation of charities in the UK and USA that have raised funds for further research and drug discovery programmes.

# 2.2 Infection and global health

We are under threat from the rise of antibiotic and antiviral drug resistance, emerging and spreading infections (e.g. Influenza, Ebola), and the resurgence of diseases once thought conquered (e.g. Tuberculosis, Polio).

**What’s the challenge?** Current techniques of screening for new therapeutics offer a brute force approach that is costly and inefficient. The pipeline of new anti-infective agents is dangerously low. We need news ways to combat the threat of infectious disease by generating better weapons to protect against them.

**What’s our aim?** To counteract emerging threats in infection by integrating our understanding of how a pathogen interacts with its host across scales – from molecule, cell, organism and population – over evolutionary timescales and within an ecological context.

We will pursue alternative approaches to combating infection such as exploring ways to extend the life span of existing drugs by more optimal application. We will develop innovative strategies to delay or prevent drug resistance emerging such as using evolution-proof or anti-virulence therapies or by increasing the host’s tolerance to the infection without killing the pathogen. We will use the power of gene sequencing to predict and track the emergence of new pathogens and drug resistance and so provide an early warning system to limit their impact.

Recognition of our resident expertise by the Welcome Trust led to investment in 2011 in a Centre for Immunity, Infection and Evolution. We can generate even greater returns on this investment by developing a joined-up approach to infectious disease control, by integrating basic pathogen biology and immune function (and dysfunction) analysis.


## On the trail of an epidemic

Professor Andrew Rambaut and collaborators in New Zealand and the USA have developed computational methods for the analysis of gene sequence data from viruses and bacteria to investigate their evolutionary and epidemiological dynamics. Information about the timing and location of the origins of human and animal epidemics can be traced and the rate of spread measured from a relatively small sample of isolates from the population of infected individuals. The software – so called BEAST (for Bayesian Evolutionary Analysis Sampling Trees) – now plays an important role in analysing and responding to global pandemics (e.g. Ebola, H1N1 swine-flu).

# 2.3 Synthetic biology

Synthetic biology brings together biologists, chemists, engineers and computer scientists to create reusable, systematic methods for increasing the speed, scale, and precision with which we engineer biological systems. Synthetic biology is a new biology-based toolkit that will enable transformative improvements across many industries.

**What's the challenge?** Synthetic biology is still in its infancy. We still need to develop the insight, tools and techniques to enable biological engineering so it can deliver affordable and effective health solutions, food security, greener and cost-effective forms of energy, and new materials to supply our growing global population.

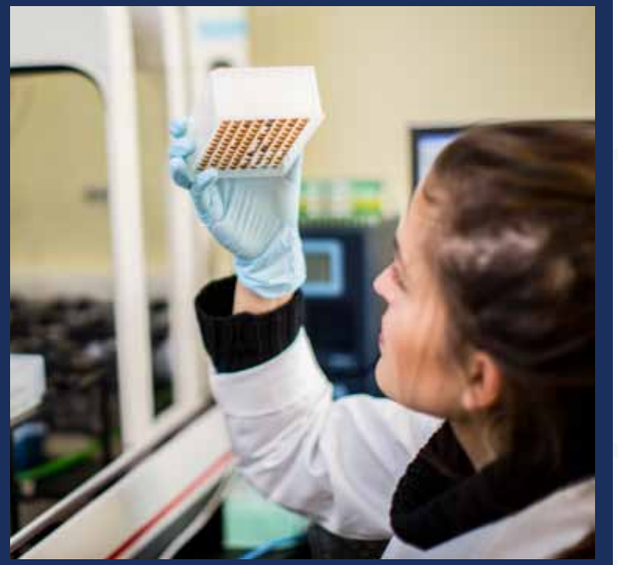
**What's our aim?** To develop and use the techniques of the new science of synthetic biology to design and build biological circuits and generate bespoke systems.

We will provide a powerful new generation of research tools to model, design and test understanding of biological processes and systems and to underpin our aims in epigenetics and infection research. Allied to this will be the development of policy guidance for responsible research and innovation.

We will design and build sophisticated biological circuits with controllable and specified characteristics and incorporate these into living hosts. Assembling very large DNA sequences has become feasible only recently and in just a handful of places including Edinburgh. This will transform the current rather piecemeal manipulation of the genome, where a few genes are modified at a time, to that of exquisitely-controlled engineering of thousands of genes. Biologists will then be able to learn by building, as chemists have done for centuries.

## Foundries of the future

Professor Susan Rosser and Dr Patrick Cai have been awarded >£5 million from the UK's Biotechnology and Biological Sciences Research Council to assemble a state-of-the-art 'factory' for DNA. The aptly named Edinburgh Genome Foundry will both design and assemble large fragments of DNA – the building blocks of life – using a highly automated platform of computer-controlled robotics. The vision is to provide cost-effective, end-to-end design and building of 'big DNA' (up to 1 million base pairs in length) for applications in synthetic biology and industrial biotechnology. The ability to efficiently construct large and complex pieces of DNA will allow researchers to, for example, program stem cells for use as medicines, detect the multiple changes in cancer cells, build synthetic viruses to make more effective vaccines and engineer cell factories for novel drugs or 'greener' chemicals and biofuels – all of which will contribute to the new bioeconomy.



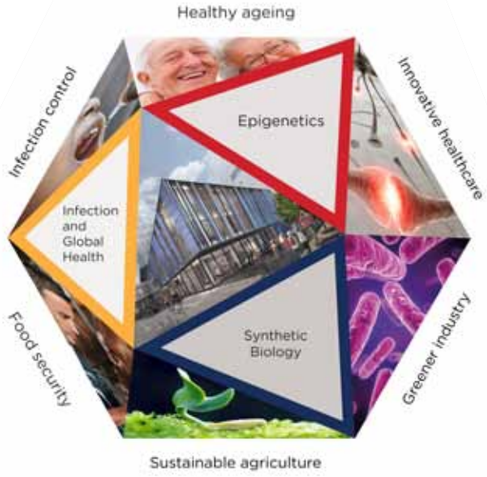
# 2.4 At the interface

Individually, each of these three areas of research is an exciting area for exploration but the most exciting, and perhaps unpredictable, discoveries will be those that arise from interactions and synergies between the themes.

Just some examples of outcomes from future interactions are outlined here.

- **Synthetic biology** will impact on **infection biology**. We can re-synthesize ancestral pathogen genomes, to predict how drug resistance emerges and to test whether epigenetic changes to gene expression contribute to pathogenicity of Malaria or HIV or resistance to antibiotics or antivirals.
- The interactions between **infections and epigenetic mechanisms** are comparatively unexplored and ripe for exploitation. We can start to explore how pathogens might hijack the host's epigenetic mechanisms to evade immune responses and to prolong infection.
- We can use **synthetic biology** to deliver tools to help us explore the **epigenetic control of genes**, which might facilitate high throughput drug screens for chemicals useful as drugs to treat a range of diseases including cancers and inflammatory disorders.

Our plan to co-locate our best scientists in high quality, flexible laboratory space that engenders a culture of interaction will give us the best chance of producing transformational research and innovation that can address some of the challenges facing society today and tomorrow.



# **CHAPTER 3:** A blueprint for growth

Our three themes underpin our ambitious science-led plan to harness the potential of the new revolution in the life sciences to address some of biology's most intellectually exciting questions. This will benefit our research community, our students, our investors, our economy and our society. To realise this vision we will execute an ambitious development plan around clear goals, at the heart of which is to increase our research capabilities and to enhance the impact of all that we do.

**Our goals**

We have an ambitious long-term vision for our School and by 2025 we aim to:

- Create an integrated environment for cross-disciplinary collaborations that push the boundaries of knowledge;
- Increase our research volume by 50%;
- Double the economic and social impact of our activities;
- Increase by 50% the number of postgraduate students that we train;
- Deliver innovative approaches to teaching to meet the demands of biology for the 21st Century.

To achieve these goals we need to support new and existing talent, to promote collaborative working, and to provide fit-for-purpose infrastructure that meets the needs of modern biologists.

# 3:1 Our people

Our reputation is built on the excellence of our research and teaching and therefore the people who deliver this. Today, research is an international pursuit and competition for talent is fierce. Prospective students demand quality and value for money and have a wide choice of providers.

We have recently invested in recruiting established leaders and inspiring early career scientists in epigenetics, infection and synthetic biology to continue to build strength and capacity in our strategic research areas.

We have established new Chairs in synthetic biology, epigenetics and science education. We have also recruited 20 Chancellor's Fellows – a cohort of international 'rising stars' that have the opportunity to establish their research careers in Edinburgh. Our Fellows bring energy, enthusiasm and ideas to our community and bring new expertise across our three key themes.

We will continue to attract, support and develop new and existing staff to meet the needs of our emerging research interests and our students, and therefore to maintain our competitiveness and excellence for the future.

## Leaders for the future

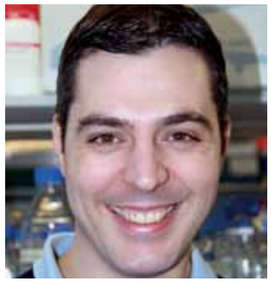
Professor Susan Rosser holds a Chair in Synthetic Biology at the University of Edinburgh. She is Director of the Edinburgh Mammalian Synthetic Biology Research Centre, Co-director of the Edinburgh Genome Foundry, and holds a prestigious EPSRC Leadership Fellowship in Synthetic Biology. Susan's research focuses on developing synthetic biology tools for pathway and genome engineering in bacteria, yeast and mammalian cell systems. The applications of her work include rapid strain engineering for production of high-value secondary metabolites, cell lines for protein production, engineering bacteria to generate electricity and developing genetic tools for bio-computation: engineering cells to sense, process and memorise information. Previously Susan was a lecturer in the Institute of Molecular, Cell and Systems Biology at the University of Glasgow before being promoted to Professor in 2012. Susan first studied microbiology and genetics at the University of Dundee before doing a PhD on the mechanisms of multiple antibiotic resistance. She then moved to the Institute of Biotechnology at the University of Cambridge to work on the biotransformation of cocaine and high explosives.



# Profiles of some of our rising stars

## Alistair McCormick

Alistair McCormick is interested in the carbon fixation process of photosynthesis in plants and algae. The efficiency with which plants fix carbon is a major determinant of crop yield. Alistair is applying synthetic biology-based approaches to re-engineer photosynthesis in plants to increase yield and the resistance to stress such as drought and heat. Alistair gained a PhD from the University of KwaZulu Natal while working at the South African Sugarcane Research Institute. He has subsequently worked as a postdoctoral fellow at the Universities of Oxford and Cambridge and the John Innes Centre in Norwich.



## Teuta Pilizota

Teuta Pilizota is interested in learning what happens when bacteria get stressed by watching, in real time, exactly what happens in a single living cell or even a single molecule. For this she is developing novel sensors of a cell's physiological state by integrating state-of-the-art fluorescence imaging techniques, microfluidic devices and optical techniques. The entwined nature of different stress response networks makes these types of measurements crucial for understanding and subsequently controlling bacterial cell cycles. Teuta obtained her PhD in biophysics from the University of Oxford and then did post-doctoral training at Princeton University before moving to Edinburgh.

## Liz Bayne

Liz Bayne explores the mechanism, regulation and functions of RNA-directed chromatin modification, focusing on yeast *Schizosaccharomyces pombe* as a model organism. Liz did her PhD with Professor Sir David Baulcombe at The Sainsbury Laboratory in Norwich. Her PhD focused on the role of RNAi as an antiviral defence mechanism in plants but she switched to looking at yeast when she became a postdoc in the lab of Professor Robin Allshire. In January 2011 she set up her own lab at the University of Dundee, supported by an MRC Career Development Award, and in October 2012 returned to Edinburgh.

# 3:2 Our culture

History has shown that breakthroughs in science often occur at the interface between different disciplines. To retain our ability to deliver world-class research we will continue to support a culture of cooperation and collaboration across Biological Sciences – and indeed beyond – to encourage cross-fertilisation of ideas and expertise using a variety of strategies.

**Seeding Collaboration:** Many great ideas are lost in gestation because of shortage of time and resource. We hope to capture and bring more of these to fruition by providing access to small amounts of funding for exploratory projects. For example, a generous donation from the Mary Kinross Foundation has supported nine pilot projects in epigenetics, stimulating exciting new research partnerships.

**Pooling Facilities:** Shared research facilities can draw together scientifically disparate groups and encourage dialogue and knowledge exchange. Our School has several unique facilities including Edinburgh Genomics (DNA sequencing and bioinformatics) and the Edinburgh Genome Foundry (DNA synthesis). We plan to create a 'Technology Hub' to co-locate our state-of-the-art platforms, providing easy access for both academic and industry users.

**Engaging with Industry:** We plan to consolidate and broaden our connections with local and global companies and other beneficiaries of our research by focusing additional resource on this important activity. We will encourage our staff to proactively engage with industry, policy makers and the public.


## Edinburgh Genomics launched

Edinburgh Genomics was formed at the University by the merger of The GenePool (based in the School) and ARK-Genomics (based at the Roslin Institute). The facility now has the largest data production capacity of any open-access genomics facility in the UK. It was recently expanded to include the next-generation of gene sequencing machines that will enable us to sequence entire human genomes for exploring the link between genetics, disease and therapy. Edinburgh Genomics is recognised by the three major UK biological research councils (MRC, BBSRC and NERC) and supports ground-breaking research in human and animal health, evolutionary and environmental genetics, and sustainable food production.

# 3:3 Our spaces

Building a new biology means providing the best spaces and facilities for collaborative science to flourish. Even in today's world of digital communication, it has been shown that we communicate less as we move physically further from our colleagues. Creating chance encounters and unplanned interactions is just as valuable as the efficiencies that can be gained from co-locating activity.[6] Regular, direct contact between researchers from different backgrounds and specialities is proven to drive scientific breakthroughs.

To deliver the major advances that we anticipate from synergies between our research themes, we want to bring our people and facilities together in one integrated, state-of-the-art complex. To achieve this we plan a major >£100 million investment to redevelop our currently dispersed and ageing estate into a single integrated complex – the New Biology Complex – at our King's Buildings campus. We will expand, rejuvenate and integrate our current buildings into an exciting research complex where we can build a truly collaborative, interdisciplinary and outward-looking culture. This will be a transformational development for researchers, students and our local community and will inspire the next generation of biological scientists.

The **New Biology Complex** will link four of our existing buildings into a cohesive mini-campus with a total of 30,000m$^2$ (the equivalent of three football pitches) housing more than 800 scientists. The Complex will be at the physical and metaphorical heart of our School – a front door to biology in Edinburgh and a focal point for all our activities.

The first step is to strip back the **Darwin Building**, built in 1967, to its steel frame and give it a complete make-over. On completion, the re-engineered building will have double the capacity of today. The architecture will encourage rather than hinder conversation between research groups and stimulate new collaborations with its modern open-plan design.

Our technology platforms are continually being updated with new equipment to ensure that our researchers can excel in their scientific endeavours. The Darwin Building will house a **Technology Hub** co-locating state-of-the-art equipment to underpin our research challenges and to provide a magnet for collaboration. The Hub will be a test-bed for new advances in technology, whether developed internally or by industry partners. Facilities will be accessible to academic and industrial partners, some of whom are working with us to establish these capabilities on site.

The New Biology Complex will also incorporate the **BioHive**, an inspirational building providing catered, social, meeting and study facilities designed to suit a range of functions: for staff and students to socialise, for scientific conferences and seminars, for meetings with companies, for school visits and for outreach to the public in the form of exhibits and presentations. The BioHive will become a gateway to the School and offer an accessible and appealing face for biology in Edinburgh.

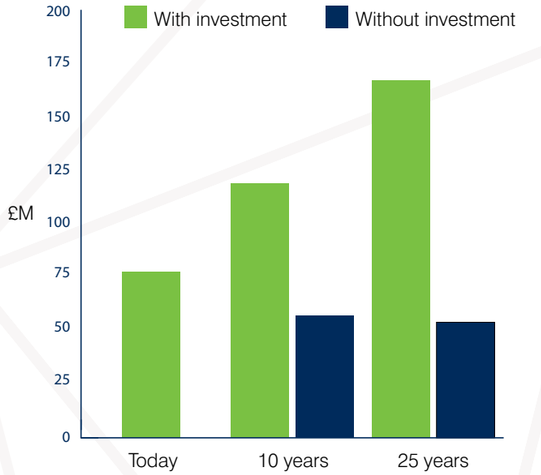
# 3:4 Our future impact

Our plan for growth and our focus on three strategic research themes will increase the impact of our activities by sustaining and strengthening world-leading research and by enhancing our ability to translate this into economic and social benefits. Alongside people and projects, we need capital investment in buildings and equipment to enable cutting-edge research, provide capacity to respond to new ideas with agility, and to provide space to forge creative partnerships with industry and governments. Not investing today will have negative consequences, compromising our ability to deliver the inspiring scientific outcomes that are well within our reach.

Our ambitious scientific development programme relies on the development of our estate. Investment in capital projects such as this can generate a significant economic benefit for local and national economies as well as for the University. An independent report evaluated the impact of the School's plans for a >£100 million investment in infrastructure.[4] This was estimated by analysing the impact of key drivers of growth for the School (income per investigator, and staff and student numbers) that will be supported by the new buildings.

Looking at the Scottish economy, the development and expansion of biological sciences at Edinburgh enabled by the proposed investment in our overall estate programme has the potential to generate at least a 220% increase on current GVA over a 25 year period (from £80 million to £177 million). Without the proposed estate development, there would be a 27% fall in current GVA in Scotland to £59 million over the same period. The difference equates to some £120 million per year, or £1.7 billion over 25 years, gained for the Scottish economy arising from the proposed capital investment, and approximately double that in benefit for the UK as a whole (using current estimates).

Armed with this assessment, we can be confident that our plans for growth are viable and that capital investment will deliver the desired increase in our impact in the future.




Scenario modelling: total annual GVA impact (£ million) 2014-2039

Capital investment in buildings and equipment is essential for sustaining our international research competitiveness.

# Conclusion

The School is a leading centre for research and teaching in the biological sciences, with an enviable place in the world in both reach and reputation. With a focus on expanding our world-leading capabilities in epigenetics, synthetic biology, and infection and global health, we have exciting plans to build on this reputation and enhance our impact on solving real-world problems.

The so-called bioeconomy is growing, as nations look to biologically based products and processes to provide sustainable and resource-efficient solutions to address the grand challenges for our society. Our research themes offer the potential for transformational advances in knowledge and will enable Edinburgh to take a leading role in this new biology.

Integration of our themes will provide unique interdisciplinary strengths and generate profound new insights. We can achieve this integration by investing in estates and infrastructure to nurture and support interdisciplinary collaboration.

To build an exciting new campus for biology in Edinburgh requires a substantial investment. We are engaged in a programme of fundraising and partnership development to ensure that we can deliver all of our ambitious aims. We have strong foundations on which to build and a credible strategy for growth. We are convinced that investment today will deliver a long-lasting return for our School, our students and society as a whole as we build a new biology in Edinburgh.

# References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