



Llywodraeth Cymru
Welsh Government

www.cymru.gov.uk

Science for Wales

A strategic agenda for science and innovation in Wales

Important note

The word 'science' is used throughout this document to represent the widest possible range of subjects, to include the STEM subjects (science, technology, engineering and mathematics), including the components physics, chemistry and biology, and also computer, environmental, e-science, health and medical, and social sciences. It is used as an all-encompassing, inclusive abbreviation.

Similarly, the term 'scientist' is used as shorthand for physicist, mathematician, technologist, engineer, social scientist, and so on.

R&D is Research & Development.

RD&I is Research, Development & Innovation.

*PET/CT Scanner internal view – Cardiff
University PET Imaging Centre, Heath, Cardiff.
Credit: Cardiff University*

*The cover artwork is based on genetic
data formats, primarily barcoding.*



ISBN 978 0 7504 7150 3 / WG14478
G/MH/4247 / March / Typeset in 12pt
© Crown copyright 2012

Science for Wales

Contents

Foreword by the First Minister of Wales and the Minister for Business, Enterprise, Technology and Science

Executive Summary

Introduction by the Chief Scientific Adviser for Wales

1. The Welsh Government and Science

2. An Overview of Science in Wales

- 2.1 Science in Wales now
- 2.2 Research funding
- 2.3 Excellence and focus for economic impact
- 2.4 Partnership with the best
- 2.5 National assets and inward investments
- 2.6 Fundamental science research
- 2.7 The critical importance of the educational base
- 2.8 The need for stability
- 2.9 Leadership for science

3. Strengthening University Science

- 3.1 The universities
- 3.2 Improving practice in winning competitively funded research
- 3.3 Getting the most from EU structural funds
- 3.4 The Grand Challenge priorities and the cross-cutting base
- 3.5 Raising research quality: Sêr Cymru and National Research Networks
- 3.6 Actions: universities and the research base

4. Promoting Business Innovation and the Exploitation of Science

- 4.1 Innovation promotion
- 4.2 Next steps
- 4.3 The digital economy
- 4.4 Managing and exploiting intellectual property
- 4.5 Actions: innovation and industry

5. Increasing the Science and Engineering Talent Pool

- 5.1 STEM for education and society in Wales
- 5.2 Matching the supply of STEM-related skills to demand
- 5.3 The National Science Academy
- 5.4 Actions: the promotion of STEM

6. Improving Delivery in Government

- 6.1 Strengthening leadership in science
- 6.2 Tracking and overseeing delivery
- 6.3 Outcomes

Appendix 1: Inaugural members of the Science Advisory Council for Wales

Appendix 2: Higher Education in Wales – numerical evidence

Appendix 3: An analysis of Wales' strengths in the three Grand Challenge priority areas:

- A3.1 Life sciences and health
- A3.2 Low carbon, energy and environment
- A3.3 Advanced engineering and materials

References

Foreword by The First Minister of Wales and the Minister for Business, Enterprise, Technology and Science



The Sustainable Building Envelope Centre (SBEC) at Shotton, Deeside. © Tata Steel UK.

Wales needs to make the best possible use of its science as it plays a part in so many aspects of our lives. We need the outcomes of scientific research not only to bring new products, processes and services to the market but also to bring improvements to our health, natural environment and broader welfare.

Wales' universities have some truly world-class research teams. We should celebrate their reputation and successes, but we need a sustained and committed effort by many more of our academics. They must be ambitious to gain competitive funding for inventive and challenging science research. They must be proactive in collaborating with the best in their field, wherever they are

in the world. They must engage fully with increasingly competitive research funding processes and win a greater share, both individually and collectively.

A well-taught, relevant and engaging science curriculum can be hugely stimulating for our children and young people – dealing as it does with the fundamentals of our world and our life on it. We must ensure that enough school pupils are inspired to study sciences in sufficient depth to be able to go on to study science-related subjects in further and higher education and move into scientific-based careers.

A central ambition of the Welsh Government is to build a stronger

economy. A sound and vibrant scientific and technological base has substantial potential to boost the economy, through advanced ideas, skills and developments and an effective translation through innovation to more high quality jobs.

Placing science in the portfolio of the Minister for Business, Enterprise, Technology and Science demonstrates just how important the link between science and the economy is to us.

To succeed in a globalising world economy we must play to our scientific and business strengths. Building on our higher education, health and industry sector strategies we have identified three Grand Challenge priority areas: Life sciences and health; Low carbon, energy and environment; and Advanced

engineering and materials. We will build and develop our research and business capabilities in these priority areas.

Science for Wales sets out a compelling vision for where Wales should be going in the future in research, science teaching and the commercialisation of research for economic gain. In appointing our first Chief Scientific Adviser for Wales we expected to see a critical and evidence-based approach brought to bear on our revised plans for science in Wales. This strategy tells some hard truths but offers a constructive way ahead both for what the Welsh Government can do to help science thrive and for what we expect our partners in higher education and business to address, to make this strategic agenda a reality.



A handwritten signature in black ink, reading 'Carwyn Jones'.

Rt Hon Carwyn Jones AM
First Minister of Wales



A handwritten signature in black ink, reading 'Edwina Hart'.

Mrs Edwina Hart AM OSJ MBE
Minister for Business, Enterprise,
Technology and Science

Executive Summary



The most advanced university-based lightning testing facility in the UK.

The Welsh Government Vision

- Our goal is to build a strong and dynamic science base that supports the economic and national development of Wales.
- Government can support and lead towards this goal, but success ultimately depends on the research, business and education communities. We have some building blocks in place, but need to improve across a range of areas.
- Wales has some world-class science but won just 3.3 per cent of UK Research Council funding in 2009/10. Greater than 5 per cent is our target. Researchers must raise their ambition and do better. If we are serious about developing our science base, we must change our approach and we must create a step change in activity.
- We need to create an environment where learners want to study science, perform well internationally at school level, and progress in science-related careers, delivering excellence in industry and world-class standards in further and higher education.
- To achieve this we will focus our energies through our education and business support systems, concentrating on key sectors to promote an economy where science is a major generator of wealth and prosperity. We will launch a programme of targeted interventions to help place Wales on a global stage.
- We recognise the vital links between the research and science skills base in Wales, and the processes of innovation, development and commercialisation that transform scientific outputs into economic advantage for Wales. A strong, advanced industrial sector depends critically on the science base. They each should feed one another. In this context, we are interested in ideas for closer linking between the research, the innovation, and the commercial development stages of projects.
- We need to invest in the science base in Wales, because, as we identify in this document, it needs strengthening if we are to be competitive. But we also need to focus on our strengths.

Delivery

- Having reviewed current strengths in Wales we will launch a programme in three Grand Challenge priority areas: Life sciences and health; Low carbon, energy and environment; and Advanced engineering and materials. These build on areas where Wales already has a track record of excellence, and where the route from research to commercialisation is reasonably clear. The strengths are real, but we are still a long way from reaching our full potential. By focusing on the Grand Challenges we aim to concentrate our efforts and increase our prospects for success.
- Our programme in these three Grand Challenges builds on a base of four vital underpinning capabilities: fundamental research; STEM outreach; the e-infrastructure; and exploitation of intellectual property. These also must be maintained in excellent shape. Much has already been done through the foresight of our universities, funding agencies and businesses, but much more is needed.
- In this strategic agenda, we identify principles to guide our progress, including clear leadership and the pursuit of excellence, world-class research, international openness in cooperating with the best, funding stability, readiness to take risks and systematic engagement with research funders.
- Finally, we discuss how support for science can be closely coupled with the wider innovation agenda and our aim to set up mutually supportive leadership in both areas.



Measuring carbon dioxide emissions from an upland heath. Credit: Centre for Ecology and Hydrology, Bangor.

The Welsh Government will:

- target achieving at least parity in competitively funded research with the other UK nations, as a first step.
- set up a new initiative called 'Sêr Cymru', which will comprise two elements. The first of these will be the setting up of National Research Networks, each led by a specialist director, for each of our three major Grand Challenge science activities, and possibly in other areas deemed to be a priority to support the Grand Challenges. The second will be an attractive scheme to bring in new global 'stars' to work in Wales, principally for the three Grand Challenges. Depending on the success of this venture, further investment in supporting research areas might be considered.
- recognise the importance of maintaining the strength of the four underpinning activities identified above, possibly through the new National Research Networks concept.
- work to deepen academic-business partnerships and encourage collaboration with the very best research groups across the world. This will include considering

proposals for closer integration of the research, innovation and commercial development stages of the national programme.

- improve the health and well-being of the Welsh population by ensuring effective translation of health research to benefit our people and the Welsh economy.
- engage more young people in science through the National Science Academy.



Playing with a plasma ball at Techniquest, Cardiff Bay.

- seek international excellence via education and training, through our schools, further and higher education sectors, and through the training provided in the work place in apprenticeships and other work-based learning schemes.
- strengthen coordination and leadership in all stages of building our science base – through the Chief Scientific Adviser and the Science Advisory Council for Wales; the National Science Academy; our universities; our industry sector panels; a new strategic advisory group for innovation; the Higher Education Funding Council for Wales; a new Labour Market Intelligence Unit; and enhanced careers advice, as well as European Funding. We will seek

greater collaboration across all sectors as we seek to build on our national strengths.

- bring forward a complementary strategy for innovation, both research-related and broader innovation, to boost competitiveness of Wales' businesses. This new innovation strategy will build on the basis set out in Science for Wales. Once this strategy is established, consideration will be given to appointing a national leader for innovation.
- under a new Chief Scientist's Department, including a new Science Division, bring clearer leadership within the Welsh Government to delivering science strategy, improving research capability and the use of science in policy.

Introduction by the Chief Scientific Adviser for Wales



The inaugural meeting of the Science Advisory Council for Wales – December 2010.

This strategic agenda *Science for Wales* has been prepared for the Welsh Government by a team comprising the Office of the Chief Scientific Adviser for Wales and members of the Science Advisory Council for Wales (See Appendix 1), and has benefited from a wide consultation with stakeholders throughout Wales. Thanks are due to all those who have given their time and effort to help us formulate this document.

Science for Wales has also been discussed with the First Minister and members of the Cabinet on several occasions, and their guidance and steer has been strong. The document now gives a clear direction to the vision that the Government has laid out above and supersedes *A Science Policy for Wales 2006*.

Wales has some great scientific strengths. These underpin much in our society, culture and economy. The Welsh Government wishes to ensure that we all build on them. Our review shows

that we could do so much better. This document is to some extent a wake-up call. To realise the Welsh Government's vision, expressed above, we need to up our game in a number of ways. This is examined in what follows.

Science touches most things in our lives, and has the capacity – if intelligently and selectively used – to improve our people's welfare, health, lifestyles and self regard. Wales can be a small, clever nation, but we must understand that this will only bear fruit if we work very hard, and with focus. No one owes us a living. The timing is urgent – for much of what we call for we need to see significant changes for the better within 3 to 10 years. If we do not seize the great opportunity before us, we will not realise those benefits. If we do take action, we can use a stronger science base to support a better economic future for our people.

Professor John Harries

Chief Scientific Adviser for Wales

1 The Welsh Government and Science

This strategic agenda sets out the Welsh Government's vision for science, the key initiatives we will take, and how we will measure success.

Excellence in science and its exploitation is a vital enabling capability for delivery across our *Programme for Government*.¹ It is central to our ambitions to create economic growth and higher added value employment in a more innovative economy. More widely it underpins our aims for healthy living in a resilient environment with more sustainable natural resources and valuing national culture and heritage.

Research and innovation takes place in businesses, universities and research institutions. These are increasingly globally connected. Governments cannot displace the central role of these primary actors. Past government attempts to identify and back a few narrowly focused industrial innovations have a poor record of success. But governments can create the conditions under which research and innovation can thrive, they can make vital investments to build capability and they can use their influence to remove barriers for innovators and promote change.

The Royal Society has argued for placing 'science and innovation at the heart of the UK's long-term strategy for economic growth', whilst also noting that the transition from research to innovation and economic benefit is not a simple linear process.² Research focused on one issue can often produce a positive result in another context.

This document sets out what we will do as a government and how we will evaluate progress. We recognise that success will depend critically on the

actions of others as well as our own – on businesses, universities and researchers as well as decision makers and funders in the UK and Europe. We aim to strengthen our partnerships and exert influence on these key partners, looking to them to create and capitalise on opportunities.

Building science and innovation capacity is a long term endeavour. It requires a sustained and consistent approach if we are to achieve impact in economic, environmental and societal outcomes.

Over the coming years we will assess progress against our measures of success, evaluate initiatives and target future activity accordingly, reporting as appropriate within the framework of our *Programme for Government*.

Our goal is to build a strong and dynamic science base that supports the economic and national development of Wales.

Specifically we aim:

- to increase our share of UK Research Council funding from 3.3 per cent in 2009/10 to 5 per cent. Wales' percentage of the UK population is 4.9 per cent. Our first aspiration is, within five years, to exceed that percentage of UK Research Council and other competitive research funding.
- for the proportion of research achieving 3* and 4* quality and impact levels in Wales' universities to reach the highest UK level (55 per cent achieved by England), or its equivalent, in the new Research Excellence Framework (REF).³

Principles that will guide our actions include:

- judging research and researchers by the REF standards of 'excellence' and ensuring that high quality, front rank research success is broadcast and celebrated.
- long-term commitment to science and innovation projects, whilst continuing to intervene where necessary to redress project delivery problems.
- more focused and selective priorities for R&D funded from Welsh resources, aiming to build capability that acts as a platform for further success.
- stronger coordination of resources and priorities across government, academia, industry, EU structural and research programmes to allow more focused delivery and raise impact.
- re-structuring universities to increase impact and scale, whilst promoting excellent existing research and recognising and appreciating the value of key national science-related assets.
- actively looking to collaborate with the best elsewhere, wherever this may be.
- tracking and pursuing UK and European opportunities to attract institutions, facilities, science and innovation capability and investment into Wales.
- strengthening technological innovation relationships with anchor companies including possible wider use of the Foundation model⁴ as a mechanism for joint investment.
- emphasising the importance of education to the science base, especially the value of high quality teachers.

2 An Overview of Science in Wales



Gas Chromatography Mass Spectrometer – Cardiff University School of Engineering.

2.1 Science in Wales now

There are demonstrably excellent activities in Welsh universities but we are not doing as well as we should for a nation of our size and aspiration. Action to improve Wales' foundation of science to underpin economic improvement is needed now.

The Research Assessment Exercise (RAE) 2008 (see Appendix 2 Table A2.1) placed 49 per cent of Welsh science in the two highest categories: 14 per cent was rated 4* 'world-leading in terms of originality, significance and rigour' and 35 per cent was rated 3* 'internationally excellent in terms of originality, significance and rigour but which nonetheless falls short of the highest standards of excellence.' This high quality research is commendable, but it also means that 51 per cent is not so placed and we must improve this. For

comparison, the respective percentages not in 3* or 4* in Scotland and England are 49 per cent and 44 per cent.⁵ There are other measures: for example, Welsh academics do well in terms of publication and citation measures, with citation impact rates now exceeding the UK average⁶, but we are under-performing in the vital area of attracting top class research funding. Building on the Higher Education Funding Council for Wales (HEFCW) decision not to fund 2* research, we will encourage excellence.

While we have some objectively measured 'world-class' researchers, a significant proportion of our research is not and should not be claimed to be so.

Conversely, some of the most exciting and impressive work is not being publicised as much as it should and needs better dissemination by universities and businesses.

There is a wide range of scientific activity across Wales, from fundamental research, through translational and applied science, to work at the interface with business. All have their value in the national context – contributing to a wide range of individual needs and purposes across Wales.

2.2 Research funding

On average, universities in Wales win relatively low levels of competitively-awarded research funding compared with the UK as a whole.⁷ In 2009/10 Wales' percentage of UK Research Council income was 3.3 per cent compared with Scotland's 14.8 per cent, having only 8.4 per cent of the UK population (see Appendix 2, tables A2.2 and A2.3). No Welsh university appears in the Times Higher Education's list of the world's top 200 universities for 2011-2012.⁸

This performance may partly be explained by the profile of research interests in Wales' universities, which on average tend towards Research Councils which are not high spending and away from those making larger grants such as the Engineering and Physical Sciences Research Council (EPSRC).⁹ It is, nevertheless, unacceptable.

Businesses in Wales generally invest less in R&D than the UK average (£244 million in 2010, 1.5 per cent of UK total).¹⁰ They also access lower than UK levels of funding from the EU Framework Programme. This possibly reflects the nature of the businesses in Wales.

The report overseen by the then Deputy Minister for Science, Innovation and Skills,¹¹ research by HEFCW,¹² feedback from Research Councils, and a review by the Science Advisory Council for Wales all suggest several probable causes of under-performance. These include insufficient high quality proposals from universities.

There is often a preponderance of individual, small applications compared with funders' expectations for larger, more ambitious and challenging proposals, often requiring a multi-institutional cooperation. Another factor is the effective use of EU structural funds in building research competitiveness. Structural funds must help improve our infrastructures and capacity, as in the establishment of the Low Carbon Research Institute (LCRI),¹³ the Institute of Life Science (ILS)¹⁴ and the BEACON Wales project,¹⁵ to lever additional funds from the tougher competitive routes. It is not to be regarded as a substitute for research funding competitions.

The Welsh Government remains committed to the 'dual support' system of funding the best university research through the distribution of Quality Related (QR) funds from which to launch bids for competitive funding from UK Research Councils and elsewhere.

New sources of funding to boost research excellence in Wales are considered below.

2.3 Excellence and focus for economic impact

'Excellence' is the important criterion for judging the quality of research, be it basic or applied science. This is not to deny the vital importance of impact and 'transformative ability' for the economy of Wales for much applied work. Wales must rely on objective, factual evidence to judge excellence, or impact – always relative to the best in the UK and beyond.

Excellence in science is an 'attractor', and can draw in people, investments and facilities, especially if associated with a 'star' scientist. To achieve excellence in research or in innovation and commercialisation we must ensure

we are competitive in today's world as judged through objective assessments, such as the up-coming REF process, or the more subjective annual World University Rankings which broadly measure 'reputation'.

Most important, Wales has to improve its performance in winning external, competitive research or R&D funding. We need to bring in from the rest of the UK, from Europe, and from further afield, at least a proportionate amount of the competitive research funding available. This means funds from the UK Research Councils, the Technology Strategy Board (TSB), the EU Framework programme (FP7 and the upcoming Horizon 2020) and major charities. These research funders have the highest standards of peer review, so winning their funds is a true test of our international excellence.



Detector array for ESA's Planck satellite, which operated in space at a temperature of 0.1 degrees above absolute zero. Credit: Cardiff University, School of Physics and Astronomy.

Some significant industrial research is undertaken in Wales. Business engages with universities in and beyond Wales

in research to advance its products, processes and services. Figures overall remain low compared with UK averages. In 2010, Business Enterprise Research and Development (BERD) expenditure for Wales was £244 million, representing only 1.5 per cent of the UK total. Although Wales does not host head offices for its major businesses (noting that in-house research functions can follow head office location) there is still supportive action we can take to improve our position.

The *Programme for Government* highlights the main actions, such as:

- 'The building of strong links with our anchor companies...embedding them in the Welsh economy by developing close links with our further and higher education institutions.'
- 'Encouraging collaboration between our universities and the best universities outside Wales...and the scientific knowledge and expertise of our world-leading academic groups to be made available to support innovation and job creation in Wales.'

In all this, as a small country in difficult economic times, we have to be selective, focusing on a limited number of key priorities. Hard choices need to be made, again relying on objective, factual evidence and comparison with the best.

Wales' businesses can also exploit discoveries made elsewhere. The Welsh Government has already stated it will support high performing, quality companies in all those parts of the economy which can create employment, wealth and a sustainable Wales.¹⁶ It has focused its limited resources on working with such businesses and research activity in key sectors.¹⁷ Three of these sectors are particularly 'science-intensive' and are priority areas for the strategy, they are:

- Life sciences
- Energy and environment
- Advanced materials and manufacturing

In developing this strategy, the advice of the Science Advisory Council for Wales has helped identify three priority research themes where our scientific research is strong and can assist these sectors. These Grand Challenge priority areas are discussed elsewhere (section 3.4 and Appendix 3). They are:

- Life sciences and health
- Low carbon, energy and environment
- Advanced engineering and materials

We also aim to underpin these Grand Challenge priorities with four cross-cutting themes:

- STEM outreach
- e-infrastructure
- IP exploitation
- fundamental ('blue skies') research



Four point probe measures conductive tracks printed on a biosensor by Swansea University's Welsh Centre for Printing & Coating.

2.4 Partnership with the best

The Welsh Government is committed to making Wales a 'learning country, [where] large numbers of highly skilled and highly qualified people are employed in high technology, high added value companies...' ¹⁸ To succeed, we need capable organisation, a widely-accepted culture of excellence, good education and effective links between academia and business.

Wales has to look outwards. Our ambition has to be to work with and compete with the best in the world. While the Welsh Government is committed to a strong framework for science and its applications, scientists must propose imaginative and creative new projects and show increasing ambition to win funding for these. So many sources of funding lie beyond our borders – not just in the UK and the EU but through research agreements with India, China, the USA and elsewhere. ¹⁹ The Welsh Government wishes to see far greater engagement in such collaboration and stronger links between higher education and industry.

Scientific research is undergoing a steep rise in the amount of multidisciplinary and collaborative work needed to achieve results in complex subjects, often at the boundaries of conventional disciplines. Wales is well placed, being small and hence less complex and with a devolved government, to build collaboration. The Welsh Government wants to see universities, institutes and industry in Wales become more ambitious and increasingly engaged with the best groups.

The Higher Education Funding Council for Wales (HEFCW) has called for universities to restructure in order to increase scale, ²⁰ and to increase collaboration to deliver a stronger and

more sustainable higher education sector, with this message reinforced by Professor McCormick's report for the Welsh Government.²¹ There is valuable experience in research collaboration to build on in Wales, along the lines of the successful 'research pools' in Scotland, which we intend to adopt in the 'Sêr Cymru' initiative, described later.

2.5 National science assets and inward investments

Some national assets underpin and contribute to our science programmes through their science teams, facilities and public engagement. Examples include many we can be proud of: the National Library of Wales in Aberystwyth; the National Botanic Garden of Wales in Carmarthenshire; the National Museum of Wales in Cardiff; the Centre for Alternative Technology (CAT) outside Machynlleth; the Darwin Centre in Pembrokeshire; the Techniquest centres in Cardiff and Wrexham; and others.

A smoke-ring shoot out in Science Made Simple's non-verbal theatre show – 'visualise'. © Kiran Ridley 2007.

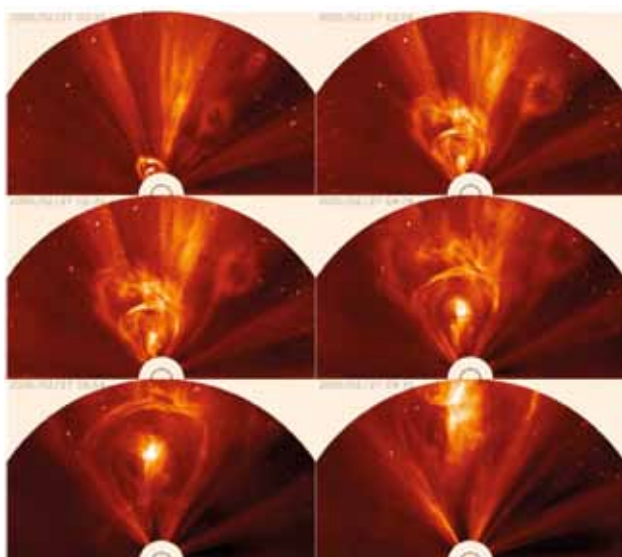
They provide a connection between the public and the world of science – attracting new recruits and maintaining a high level of public interest. They also have research programmes that contribute to and underpin important research elsewhere.

Nevertheless, there are too few UK or international facilities on Welsh soil. The Natural Environment Research Council's (NERC) Centre for Ecology & Hydrology (CEH) in Bangor²² is the only stand-alone Research Council facility in Wales. Wales does have a number of active or previous Research Council Centres or Units, embedded within universities. These are a welcome and important contribution to national science. Two excellent examples are The Medical Research Council (MRC) Centre for Neuropsychiatric Genetics and Genomics at Cardiff University,²³ and Aberystwyth University's Institute of Biological, Environmental and Rural Sciences (IBERS),²⁴ previously a Biotechnology and Biological Sciences Research Council (BBSRC) institute.



However, we should strive to capture much more inward investment through centres and institutes in Wales. The Welsh Government, along with other national organisations and individuals, aims to increase engagement with UK and European counterparts with a view to drawing in such facilities, embedded or stand-alone, to Wales' wider benefit. The impact of a major science facility coming to Wales would be substantial, as the presence of the Office for National Statistics (ONS) and the Intellectual Property Office, both in Newport, clearly demonstrate.

2.6 Fundamental science research



Improved image-processing by staff at Aberystwyth University's Institute of Mathematics and Physics shows changing profile of a coronal mass ejection from the sun (white semi-circle covers sun's disc).

Fundamental research is undertaken at the cutting-edge of scientific disciplines, usually driven by curiosity rather than any specific desired outcome. It is the core business of many science departments within Wales' universities, addressing fundamental questions about the universe we live in, at all scales of space and time and underpinning our society.²⁵ Examples of excellence in basic research in Welsh universities

include work in stem cells, genetics, nanoengineering, computer fluid dynamics, neuroscience, crop research, astrophysics, glaciology and much more.

High quality fundamental research can be an attractor: for funding, facilities, innovative companies and, most importantly, scientists who want to join the team led by a 'star'. It leads to new techniques and technologies that create activity and excitement. It is appreciated as a signal of progressive management in universities and government, and incoming companies want to share the skills and expertise that are developed. Fundamental research is strongly supported by business and the Confederation of British Industry (CBI).²⁶

It is essential that universities in Wales invest in and support their excellent teams undertaking blue skies research, and support and encourage researchers from PhD students upwards. In many cases these are teams who win substantial UK and European Research Council funding.

Wales' universities are all relatively small. Nowadays much research funding is won by larger, often multi-institutional, research proposals. That is why HEFCW is recommending substantial structural change in our university system, to enable, among other things, more research groups of the size needed for today's competitive conditions. Pooling²⁷ or networking of resources and teams will, in its own right, bring larger research teams together. Working in collaboration with excellent universities outside Wales is also to be strongly encouraged where the research interests coincide.

2.7 The critical importance of the educational base

The educational standards of our young people are critically important to the national science effort. This applies right from primary school through to higher education. The quality of school teaching is often crucial in a young person's decision to follow science. Having sufficient appropriately qualified teachers, in the separate science disciplines, is of central importance, as is the involvement of employers in bringing relevance to curricula.



Radyr Primary School pupils with the Chief Scientific Adviser for Wales at the GE Healthcare Education Zone, Cardiff.

Wales, with its relatively small scale and closely networked science population, has particularly good opportunities for promoting first-hand contact between learners and practicing scientists. Such experience and interaction can be inspirational and transformational – especially in fostering science interest and capability among under-represented groups.

We must teach for knowledge and for excellence, but also for enterprise and innovation.

There are many examples across Wales of excellence in teaching and achievement at all levels, but this needs to be

stimulated even more effectively and standards raised. Some current evidence suggests that standards in science and mathematics, for example at age 15, may not be as good as they should be,²⁸ requiring attention.

2.8 The need for stability

Science and engineering need top class people and facilities, but once the direction of travel has been set, they also need stability. Science policies and funding need to be long-term, over decades not years. This is to match the longer time frame for innovation and research, external investment decisions, career choice, and the pursuit of those careers. It can take 10 years to build a major research capability, but it can be lost by inconsistent funding decisions or uncertainty over policy or strategy. Moreover, industry will not invest if they see only short term priorities from a government.

2.9 Leadership for science

Leadership skills are needed at all levels and throughout the science 'pipeline' to ensure a higher level of scientific success and gain greater benefit from our science investments in commerce, industry and jobs. Leadership networks need to be established across the full range of sciences.

The Welsh Government recognises its own role, as set out in this strategic agenda.

Universities and industry in Wales currently demonstrate considerable initiative and creativity, but much more is needed. We expect the university sector, through its existing mechanisms, to help to build upon and implement this strategy, creating a more detailed delivery map to ensure the growth of world-class research and innovation.

UK Research Council committees, boards and councils provide the leadership to create and design new funding opportunities and ideas. We look to academics in Wales to become far more involved in these, to help in shaping research calls and not to act just as consumers. Of 89 seats available across the UK Research Councils, representatives from Wales occupy only two. Increasing this to four or five will be part of the challenge in building the capacity for more world-class academics in Wales who can be supported to engage with such activities.

application and execution. There is no doubt that in many science areas we are in a period of exciting and novel research across academic boundaries, such as between nanoengineering and medicine or advanced materials with aerospace or low carbon energy. Success requires leaders, experienced in coordinating team members from differing institutions and subject fields, who can integrate scientists from different backgrounds.

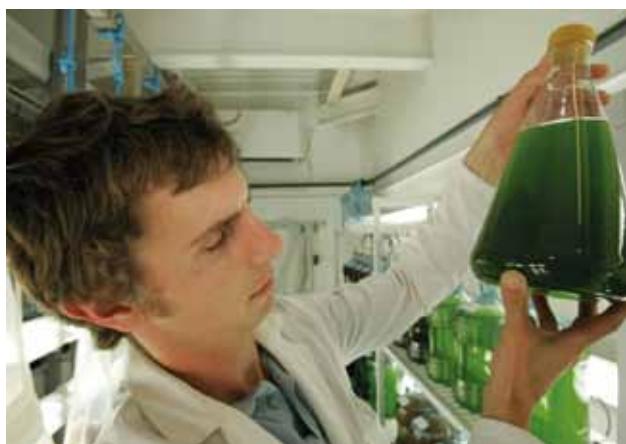


Bangor University Environmental Sciences students on a field trip in Tenerife.
© Glyn Davies.

We have said grant applications should be larger and more challenging – addressing the biggest questions of the day. We have advocated collaborations with the very best, wherever they are, becoming the norm. Individual scientists need to do a lot of preparatory groundwork, in discussions with Research Council staff, to ensure maximum compatibility of their proposal with the research announcement. Strong leadership of multidisciplinary teams, however, is vital to success in both

3 Strengthening University Science

Wales needs to coordinate its limited resources and have an overall plan to strengthen science and innovation, providing all partners with leadership and a sense of direction. Universities and industry have begun to do this.²⁹ The effort must continue, building on the opportunities in this strategic agenda. They must improve communications between groups and amongst group members. There needs to be more drive at institutional leadership level to move rapidly to a better structure for the higher education sector. Overall, better leadership, management and coaching skills in science are needed.



Microalgae cultivation at Swansea University's Centre for Sustainable Aquaculture.

3.1 The universities

Welsh universities serve a range of 'markets'. Table A2.4 in Appendix 2 shows the disposition of activity by income, undergraduate and postgraduate students. Cardiff University, our largest institution and only Russell Group university,³⁰ is very active in both research and teaching. Others, such as Glyndŵr University, Cardiff Metropolitan University and the University of Glamorgan focus more strongly on teaching undergraduate students. The spectrum of activity from

Cardiff University to, say, Swansea Metropolitan University, is wide. There are good examples of strong interactions and collaborations from both the research-intensive and teaching-intensive universities with industry. Universities contribute more than £1 billion a year in gross expenditure to the Welsh economy, in addition to their important educational and social function.³¹

The Saint David's Day Group was created on 1 March 2009, comprising Aberystwyth, Bangor, Cardiff, Swansea and Glamorgan universities. It encompasses over 70 per cent of students in Wales and more than 95 per cent of research.³² These universities declared an aim of helping Wales work its way out of recession, committing to 'Creativity, Consultation, Capital investment, Collaboration and Consensus'. It is not yet clear how much of this task has been achieved or how future development will proceed.

3.2 Improving practice in winning competitively funded research

Against a background of some excellent research in our universities, including effective operations of multidisciplinary research projects and research institutes, there is a major challenge to strengthen this science base.

An accepted characteristic of successful science organisations is that they are open and collaborative. In some cases they build 'critical mass' in selected science areas to raise competitiveness in bidding for funds.

Chapter 2 identified the urgent case for improving practice. More of our scientists and institutions need to adopt effective and strategic practice in bidding, including:

- reviewing competitive grant opportunities from all sources in planning for bids.
- proactively analysing and pitching to funders' strategies with ambition and vision.
- responding to Research Councils' demand management by setting up university mechanisms to ensure only high quality proposals are submitted.
- becoming more skilful in writing applications, following requirements carefully and producing well drafted bids that are checked with colleagues before submission.
- taking time to discuss with the funder the requirements of each research call including expected scale, size and direction. No major grant application should be submitted without this engagement.
- participating in peer review processes at all levels, up to the highest (Council member) to help guide and steer programmes. We should value service on committees, boards and councils, where new programmes are formulated, deepening understanding of programmes and how they match our interests.
- professional development and training across Wales in writing effective funding applications.³³
- systematically developing research leaders, with senior academics supporting more junior researchers' careers,³⁴ and building on HEFCW's work with the Leadership Foundation for Higher Education.
- actively promoting our successes and achievements.

3.3 Getting the most from EU structural funds

EU structural funds cannot support basic or fundamental research but can facilitate capacity building and direct interventions that increase the industrial and R&D competitiveness of Wales. They can support the development of higher skills and closer to market research with a clear business aim, and contribute vitally to making Wales more competitive in research. As such, they must only be used in a transformational way, including leverage of other, competitively awarded, funds focusing on both the creative and physical capital that will require investment. They are aligned with the key sectors and the Wales European Funding Office (WEFO) believes they can accommodate the actions in this strategic agenda without further negotiation. WEFO plan to use *Science for Wales* as a key influence for the 2014-20 programme.

WEFO need to ensure both the excellence of any research but also the extent of impact any given proposal might have. If structural funds are sought as part of a new science-related initiative, then the Welsh Government wishes to see more rigorous technical and peer review applied. WEFO currently uses a number of experts to examine science and technology aspects in proposals but is keen to increase their access to expert advice. This approach is in line with the European Commission's common strategic framework for R&D funding, which suggests closer alignment of Cohesion (Structural) Funding with the future R&D programme, under *Horizon 2020*.

3.4 The Grand Challenge priorities and the cross-cutting base

Section 2.3 introduced our approach to focusing research for economic impact. Countries with transformational

science-led economies such as Singapore have succeeded through focusing on a few areas and heavy investment in education and research.³⁵ Our Grand Challenge priority areas are evidenced as having excellent academic and clinical or translational strengths, as well as businesses in Wales that can take commercial advantage of these capabilities:

Life sciences and health – medical technology, diagnostics, cell technologies and therapies, neuroscience, health informatics, infection and immunity, cancer, genetics, wound healing, primary care, public health and human nutrition.

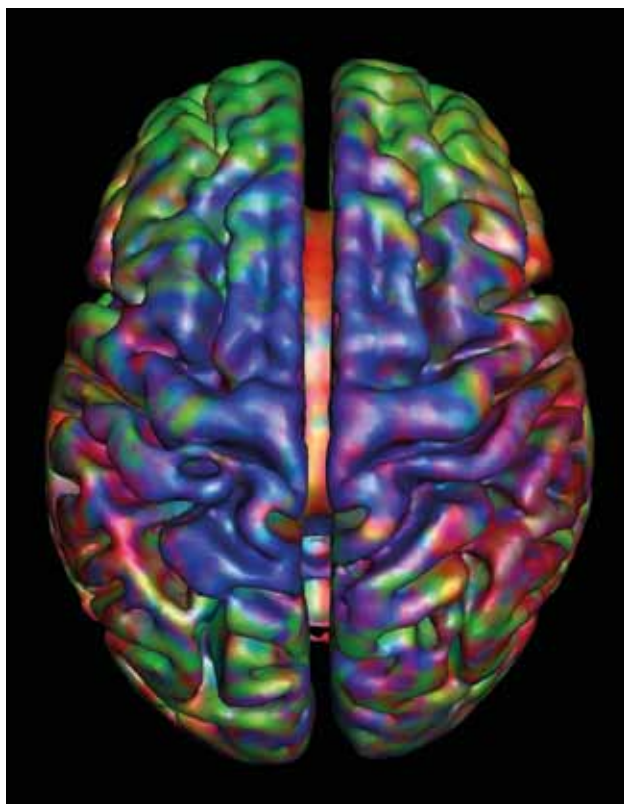


Image from Cardiff University Brain Research Imaging Centre (CUBRIC).

Low carbon, energy and environment – climate change science and adaptation; environmental monitoring, instrumentation and analysis; energy generation, efficiency, management and storage; waste management and recycling; water; ecology; forestry and crop breeding.



Baglan Bay Innovation and Knowledge Centre.

Advanced engineering and materials – aerospace, defence and automotive technologies, building on underpinning capabilities in optoelectronics, advanced materials and composites, hydrogen fuel technology and process engineering.



Cryo-scanning electron microscope – Nanotechnology research at Swansea University.

These Grand Challenge priority areas are underpinned by four cross-cutting activities: fundamental science driven by curiosity, but often the seed-bed of new ideas, concepts and inventions; the vital aspect of STEM education and outreach; intellectual property management; and a digital infrastructure necessary to underpin cutting-edge science.

Exciting opportunities for new technologies, applications and ways of working also exist in the overlap of the Grand Challenge areas. The considerable

strength in Wales in social science, including quantitative methods, can also be important in these areas, e.g. climate change, medical services, transport, food and energy.

Some of the necessary capabilities are in place already, supported through departments of the Welsh Government, HEFCW, universities, industry or non-profit organisations. The industry sector panels are developing economic sector strategies. Other parts of the programme require further action. The Science Advisory Council for Wales will address more detailed scientific issues and their conclusions will inform the evolution of the programme.

3.5 Raising research quality: Sêr Cymru and National Research Networks



Professor Michael Owen is Director of the Neuroscience & Mental Health Research Institute at Cardiff University.

The Welsh Government wants more focused action using existing and new resources to develop and raise the impact of the science base, as well as further raising its quality, in a sustainable way.

Other countries have deployed a range of institutional models and programmes. Germany supports networks of Max Planck and Fraunhofer Institutes. Science Foundation Ireland has invested substantially in world-leading researchers

and their teams and evidence suggests such arrangements are proving highly successful.³⁶ Research investment has been focused on strategic areas and in selected universities, with long-term industrial benefit in view.

An approach to research pooling has been applied very successfully in Scotland in nine or more disciplines, including traditional subjects and now some new areas which combine these traditional subjects.²⁷ The Scottish Funding Council has awarded over £40 million, with additional contributions from institutions. Scientists take a discipline-based, cross-institutional, view of research applications. They have come to regard their particular Scottish science community as a single entity. This has energised communities, and resulted in highly strategic successes in attracting major research funds. This model has relied heavily on governmental pump-priming funds and on major investments by institutions involved. Strategic planning has been led by the Chief Scientific Adviser for Scotland and Scottish Ministers, with dynamic leadership from those heading the pools ensuring truly cross-institutional behaviour and problem resolution.

The Higher Education Funding Council for Wales (HEFCW) has supported institutional research collaboration through its Reconfiguration and Collaboration Fund, with a similar scale of funding as Scotland. Amongst successful cross-university projects are those in mathematics,³⁷ non-Newtonian fluid mechanics³⁸ and low carbon science.¹³ Whilst some projects have raised impact, we have yet to see a significant increase in competitively-awarded grant funding.

We now envisage more pan-Wales initiatives, at a much larger scale.

Working with universities, their representative organisations and HEFCW, we will provide funding for new academic 'stars' ('Sêr') with supporting teams and equipment and couple this with a new programme of pooling activity across Welsh university departments – National Research Networks (NRNs).

Our aim is to improve the capability of the research community in selected disciplines so it can cooperate on proposals and projects and be more successful than to date. This approach builds on experience in Wales and appropriate elements from Science Foundation Ireland and Scottish research pooling.

To lead the NRNs we aim to recruit high impact network directors. NRNs would include existing staff who are demonstrably excellent and would also encompass the new 'stars' and their associated new fellowships and lectureships. We look for proposals to be generated with the level of expertise and excellence that will contribute significantly to the major current science and innovation issues and secure further competitive research funding. The role of the director of each NRN with their team of well-connected experts will be to make our universities more powerful and better connected with UK and European collaborators and funding bodies. Research networking can be enhanced, good practices developed, joint Masters and Doctoral Training Centres established, and research facilities managed.

Despite the challenging economic situation we face, Ministers felt this programme was sufficiently important to allocate substantial funding for a 'star' and their team within each Grand Challenge priority area. The first tranche

will support three 'stars' and their teams, set within three NRNs. Mechanisms will be set up to bring together Welsh science subject communities, to discuss priorities, to appoint a suitable director for each network and to develop proposals.

We look to the research sector in Wales to capitalise on this opportunity and add to its impact through significant co-investment.

Noting the vital role of high impact directors and the 'star' academics, the scheme will need the highest quality candidates in each discipline. As this initiative develops momentum we hope other 'big hitters' will find the academic atmosphere, funding and organisational structure attractive enough to come, or return to, Wales.



Professor Sir Martin Evans, President of Cardiff University, won the Nobel Prize for Medicine 2007. Credit: Cardiff University.

We are looking for impact across relevant disciplines including:

- new faculty positions that enhance and increase research and graduate training.
- building research excellence through theme-based strategic leadership, including directors leading and coordinating funding bids, research programmes, directions for the future and responsiveness to major opportunities.
- efficient collaborative use of state-of-the-art research infrastructure and facilities.
- a high profile Welsh Graduate School in each area, with studentships open to all nationalities.
- bids for Doctoral Training Centre awards in key subject areas, identified by the strategy.
- more effective use and development of broadband video links for research, training (e.g. elements of postgraduate training delivered pan-Wales by one source) and collaborations to overcome geography and reduce cost.
- new outward-looking interdisciplinary research links made – within Wales, within the UK and internationally.
- a distinguished visitor programme.
- an annual prize event for science and a distinguished lecture series.
- summer schools to build the reputation of Wales' universities.

With partners in higher education we aim to demonstrate to the wider world our determination to succeed in science and maximise its impact in driving economic growth.

For the first phase, after an appropriate period we will review progress. Depending on the success, there can be

further investment in more NRNs with 'stars' in the physical and biological sciences. It may also prove valuable to set up a NRN in a discipline (e.g. for fundamental research, one of the four cross-cutting subjects) to derive similar benefits across institutions, but without the 'star' component.

3.6 Actions: universities and the research base

Over the next year we will:

- launch the Sêr Cymru Programme. This will involve new National Research Networks (NRNs) of universities in the three Grand Challenge areas. We will actively seek to attract 'stars' to broaden or strengthen these Grand Challenge priorities.
- consider the support of the four underpinning activities, especially fundamental research, and examine whether NRNs could be set up to assist the growth of success in these areas. Some activities have already been funded, for example, the High Performance Computing (HPC) project.
- facilitate greater synergy between EU structural funds and research programmes in Welsh universities and industry, and improve technical and peer review of WEFO-funded research proposals.
- set up new arrangements to work more closely with the higher education sector in improving research effectiveness and encourage deeper and broader engagement with the UK Research Councils and Technology Strategy Board.
- commission a detailed study to establish the factors which determine our performance in winning

competitive research grants and research funding in Wales, including analysis of the scale and quality of proposals, success rates, funding outcomes, and the influence of EU structural funding.

Over the next five years we will:

- work to improve the effectiveness of interaction with funding agencies, raise the level of ambition, extend networks to create more powerful proposals that are aligned with funding opportunities, and promote greater expertise and professional development in grant applications amongst all university research staff.
- aim to influence higher education researchers to increase the level of funding won from competitive research sources (chiefly from the UK Research Councils) to achieve UK funding that exceeds our population fraction of 4.9 per cent.
- promote more effective research collaboration and use mergers between departments to form stronger research entities of sufficient size, reputation and excellence to attract both 'star' researchers and able junior scientists. We will encourage the development of 'critical mass' in relevant areas and in research involving a number of traditional or newly emerged disciplines in order to meet strategic needs.

The Grand Challenge priority programme

We will plan and work in three significant areas of research strength and in each of these will see appointed a 'star' academic with a supporting team under Sêr Cymru, and new National Research Networks of selected university departments – initially in the Grand Challenge priority science areas. This investment will allow us to make an early

impact on our ability to win increased funding from competitive research sources, aiming to achieve a target in five years of five per cent of UK Research Council funding. We will also promote the following supportive action, with our partners.

Life sciences and health

We will promote:

- research and innovation as core to improving health and social care outcomes.
- effective collaboration between NHS Wales, businesses and universities in Wales to enable speedier introduction of new technology into the NHS and more innovative and rapid translation of research outcomes into patient benefit and business opportunities.
- ease of contact between patients and researchers to optimise the amount, quality and diversity of health research undertaken in Wales.
- the creation of a strong life sciences and health ecosystem in Wales, to bring the whole sector together and amplify what is most excellent to a global audience. This will involve creating and supporting networks and events, bringing more focus and coherence to the whole sector, and communicating a persuasive narrative about Welsh life sciences.
- stronger arrangements for bringing together institutions, disciplines and activities. We will draw in stakeholders, partners and investors, driving projects from bench through bedside to commercialisation, and confidently projecting the sector to a global audience.
- adequate and appropriate funding for the translation and commercialisation of innovative research. This must offer

a genuine alternative to licensing and enable businesses to grow quickly from start-up to global reach without leaving Wales.

Low carbon, energy and environment

We will promote:

- pursuit of the research priorities identified in the Energy & Environment Sector Framework and focused support for businesses to embark on innovation and R&D that has commercialisation potential.
- safeguarding the long-term data sets in universities or research centres, and building on this bedrock data in future research proposals.
- sustainable ecosystem management and the secure supply of energy, within the mandate of the Climate Change Consortium of Wales (C3W).³⁹
- effective coordination by universities and research bodies in groupings such as the Low Carbon Research Institute (LCRI) and the C3W, to ensure they are credible and effective at securing competitive funding to fulfil their role.
- a stronger role for the Wales Environment Research Hub⁴⁰ in bringing together funders, researchers and beneficiaries on a regular basis to discuss and monitor strategy and delivery in this area and to identify new opportunities and collaborations.
- using public programmes, such as procurement of social housing to the highest low carbon standards, as a stimulus to pull through new environmental technologies, to drive underlying training and to build relevant firms in Wales.

Advanced engineering and materials

We will promote:

- closer cooperation between our leading engineering departments through the Sêr Cymru scheme.
- wider involvement in successful industry integration schemes such as EADS Foundation Wales.
- closer working with anchor companies undertaking industrial R&D in Wales and more anchor companies with existing manufacturing capability in Wales establishing or extending R&D capability here.
- a review of knowledge and skills-related schemes which support joint industry-university projects, to assess how well these schemes match the needs of industry in Wales in advanced materials and manufacturing and suggest appropriate adjustments.

Fundamental research

We will promote:

- excellence in our universities in the fundamental sciences.
- the expectation that most research in this category will be peer reviewed and funded through the UK and European Research Councils.
- awareness that some expenditure from other sources may be needed in order to develop research networks in specific subjects, such as physics or mathematics. Such funding may give the subject a valuable boost, for quite small investments.
- an early study of procedures for setting the level of fundamental research within our national programme of science.

The other three cross-cutting initiatives – STEM outreach, IP, and e-infrastructure – are considered in other sections.

4 Promoting Business Innovation and the Exploitation of Science

Building on an excellent science base, innovation and the commercialisation of R&D have been key priorities in recent Welsh Government economic policy.¹⁷ Innovation is also at the heart of the EU's *Europe 2020* strategy, being seen as central to tackling major societal challenges, such as climate change, energy and resource scarcity, health and ageing.

It is our intention to produce an innovation strategy for Wales in the spring 2012, building on *Science for Wales*. It is in recognition of the strong links between science and innovation that we discuss innovation here.

Other strategic publications also relate to the innovation agenda. These include the National Endowment for Science, Technology and the Arts (NESTA) *2010 Innovation Report*⁴¹ assessing UK performance in terms of human resources, intellectual property, knowledge transfer, investment in intangible assets, the role of government and R&D investment. The European Commission's *Innovation Union* policy,⁴² defining innovation as improving the way we conceive, develop, produce and access new products, industrial processes and services – changes that create more jobs, improve people's lives and build greener and better societies. The *UK Innovation and Research Strategy for Growth* (December 2011)⁴³ also recognises that innovation is a major driver of economic growth and must occur in all parts of society.

4.1 Innovation promotion

Many policies to promote innovation are set at the European or UK level, including rules on competition and state

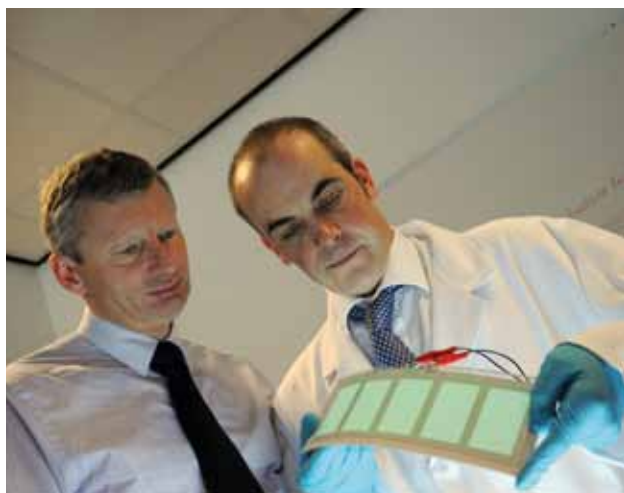
aids, sector and market regulation, fiscal incentives and R&D investment. The Welsh Government takes action through its economic development policy and has supported projects that encourage long-term sustainable investment in Wales by business and commerce, to strengthen our economy through R&D, design and innovation.

Our innovation support programme currently comprises:

- the Business Innovation programme offering support for new product development, protection and exploitation of intellectual property, design and manufacturing.
- RD&I financial support for business, supporting businesses to undertake projects from proof of concept through R&D to exploitation.
- the Academic Expertise for Business (A4B) programme supporting collaboration between higher education and business.
- Knowledge Transfer Partnerships (KTPs), a TSB initiative, helping businesses to improve their competitiveness and productivity through the better use of knowledge, technology and skills that reside within the UK knowledge base.

Wales has some very successful anchor companies such as Tata Steel UK, EADS, BT Wales and Qioptiq. These have strong links with universities and a number of collaborative arrangements in place. EADS Foundation Wales⁴ is an innovative and active joint venture between EADS, Cardiff University and the Welsh Government to cross the 'innovation

gap' between industry, universities and government. There are significant activities from the earlier Technium programme⁴⁴ such as OpTIC at Glyndŵr University, St Asaph⁴⁵ and a fair quantity of smaller collaborations in place.



Kevin Bygate of Tata Steel UK and Professor Dave Worsley of Swansea University have developed new building concepts in Project SPECIFIC.

4.2 Next steps

Although there are successful collaborations already in place, we are keen to see significantly more translation from science to innovation in Wales. *Science for Wales'* purpose is to achieve a healthy and vibrant science programme to allow for this. This raises the question of what mechanisms we need to effectively link the scientific research, innovation and commercial exploitation phases. We encourage creative thinking as to how Wales can improve these links and strengthen science-innovation-commercial exploitation pathways.

Our *Programme for Government* includes a key action to review what entrepreneurial support is needed by small firms with real potential to thrive and grow: innovation programmes can contribute to raising capabilities for entrepreneurship.

Consultation during the development of *Science for Wales* found that frequently SMEs (small and medium-sized enterprises) and individuals have considerable difficulty being able to demonstrate to potential funders the proof of concept for the idea, technique or piece of software or hardware that they want to develop. It is often necessary to demonstrate experience and competence by a proof of concept study for some Technology Strategy Board (TSB) competitive calls, for example. Both the TSB and the Welsh Government have recently introduced grant schemes which provide funding for proof of concept and proof of prototype activities, which should be more strongly promoted and advertised.

We intend to see that strategic leadership for innovation activity is made more effective, so that we can take a more active role in defining opportunities and projects for the future. We therefore propose that forming a national innovation strategy board should be considered, bringing 'innovation champions' from each of the key economic sectors together to advise the Minister for Business, Enterprise, Technology and Science on developing a national strategy.



Professor Chris McGuigan (Cardiff School of Pharmacy & Pharmaceutical Sciences) has licensed drugs, now in trials, to treat shingles and hepatitis C.

Many of these questions will be addressed in work to develop our national innovation strategy, building on the *Science for Wales* strategic agenda, which we plan to publish in spring 2012.

4.3 The digital economy

According to the relevant sector skills councils, digital technology is the single biggest lever for productivity and competitiveness across every sector of the economy. It is set to underpin the majority of future job creation in Western economies, and the export of global technology services and world-class content offers substantive opportunities for wealth generation.⁴⁶ Exports from the digital and creative industries are third only to advanced engineering and financial and professional services.⁴⁷ In Wales, we have strong and vibrant ICT and creative industry sectors. The ICT sector alone accounts for over five per cent of Welsh GVA. Despite the economic downturn, these two sectors combined have expanded by over 10 per cent in the last three years – adding nearly 600 new businesses.

Innovation based on digital technology is now the biggest contributor to economic growth in both Wales and the UK. Two-thirds of all UK private sector productivity growth between 2000 and 2007 was a result of technology-based innovation. Technology has always driven much innovation, and it will continue to do so in the future, but the real reason for this growth is that technology has become an enabler of innovation rather than just a driver.

The Welsh Government's *Programme for Government* recognises the importance of the digital economy to growth and through its Digital Wales strategy has set an ambitious agenda with real actions to help create the right environment to

ensure that Wales can capitalise on these digital opportunities.⁴⁸

Our universities are working on some of the most cutting-edge projects in the world including the £40 million High Performance Computing (HPC) project. Provided there is strong leadership to ensure full exploitation, this will give Welsh businesses and universities access to the most advanced computing technology in the world and have a major impact on high level skills development.

The Digital Wales Research Hub, set up by the Welsh Government, is expected to play an important role in promoting science, technology, engineering and mathematics (STEM) in Wales. It will build upon existing expertise within universities and businesses to make it easier and more attractive for multinational companies to access end to end research opportunities in Wales. Furthermore, the Welsh Government has set up a review of the use of technology in schools including using digital content in the classroom and developing Welsh Intellectual Property.

World leading companies such as Alcatel, BT, EADS and Sony have invested in Wales. This has resulted in significant expertise in digital technologies ranging from secure computing and communications to data storage and archiving. In south east Wales this is a regional strength. EADS Foundation Wales, the innovative joint venture between EADS, Cardiff University and the Welsh Government, operates a series of R&D projects to strengthen the sector in Wales. The foundation model is a powerful one and we believe it has potential as a vehicle for government-industry joint activity in other areas.

Large companies such as EADS and BT Wales are exemplars for achieving

long-term sustainable R&D investment in Wales. However, it is important to understand that there are more than 3,700 companies in Wales in the ICT and electronics sectors employing 32,000 people and making a substantial contribution to the Welsh economy and to developing relevant skills.

Finally, to encourage high level strategic collaboration between government and business, the Welsh Government has set up a number of industry-led advisory boards. These include the Digital Wales Advisory Board and the ICT and creative industry sector panels. We wish to see these boards playing a strong role in developing the digital economy in Wales.

4.4 Managing and exploiting intellectual property

The intellectual property system enables scientists and innovators to capture the value of knowledge and ideas developed in their work. While patents and copyright are the predominant formal intellectual property rights from science R&D, surveys show that, for both business and academia, 'know-how' often represents the most significant aspect of an intellectual property portfolio.⁴⁹ It is vital that all those engaged in Welsh science understand the important principles underpinning intellectual property management and how these relate to wider socio-economic benefit. It is important that we can fully exploit the intellectual property from scientific R&D in Wales. Training for early career researchers in this area is essential.

Intellectual property management from universities and research institutes can be a highly technical and specialised area. A single institution may not be able to command the necessary depth and breadth of expertise. Greater pooling of intellectual property management facilities was therefore

recommended in the 2003 *Lambert Review*,⁵⁰ the 2008 *European Commission IP Recommendation*⁵¹ and the *Wellings Review* (2008) of intellectual property and research benefits in the UK.⁵²

Pooling of intellectual property management may also simplify access by business or investors with exploitation capability.

Current Welsh Government support for commercialisation and universities' business engagement is routed through directly funded programmes and the HEFCW Innovation and Engagement budget. We will review options to target decisions on this funding more effectively, aiming to maximise overall impact and improve coherence and focus. We have signalled development of an innovation strategy early in 2012 in which a more detailed consideration of these issues, including follow-up to the *Hargreaves Review of Intellectual Property and Growth*,⁵³ will be addressed.

4.5 Actions: innovation and industry Over the next year we will:

- develop a new national innovation strategy, based on the framework laid out in *Science for Wales*, and publish this in spring 2012. This review will encompass the wider innovation agenda; the needs of small and medium sized enterprises; the vital links between research, innovation and commercialisation; and the science, commercialisation and intellectual property issues we have identified. The aim is to improve exploitation of UK and EU opportunities, including from the Technology Strategy Board (TSB), the recent *UK Research and Innovation Strategy* and the EU's *Horizon 2020* programme for research and innovation.

- depending on the new innovation strategy development, consider setting up an over-arching innovation strategy board, to advise the Minister for Business, Enterprise, Technology and Science, comprising sector champions, and chaired by a credible leader well-versed in the business of innovation.
- support priority funding and investment opportunities, assigning project teams to work with stakeholders on a pan-Wales basis, and work with existing strategic projects such as in high performance computing to ensure Wales takes full advantage of the investment.
- encourage Welsh involvement with the Small Business Research Initiative (SBRI) of the TSB, which encourages businesses to develop innovative solutions to major public sector challenges.
- conduct an options review to maximise overall impact of public funding for commercialisation and university engagement with business in Wales.
- undertake a review of intellectual property (IP) commercialisation models, the emerging collaborative approaches between major research-led universities and implications of the Hargreaves review of intellectual property, and recommend the best option for maximising the economic benefit from IP in universities, the NHS and businesses in Wales.
- with EADS, rigorously evaluate their foundation model and take steps to disseminate what has worked well, encouraging anchor companies to adopt 'open innovation' models such as that in operation in EADS and other companies.

5 Increasing the Science and Engineering Talent Pool

5.1 STEM for education and society in Wales



A-level Physics at Whitchurch High School, Cardiff.

The importance of science, technology, engineering and mathematics (STEM) skills at all levels was widely acknowledged by stakeholders consulted during the production of *Science for Wales*, and, indeed its predecessor, *A Science Policy for Wales 2006*. These skills were seen as essential to the development of a prosperous and sustainable knowledge economy in Wales. STEM subjects, along with other quantitative disciplines, are highly valued across a range of occupations, offering students varied career opportunities.⁵⁴

STEM outreach activities to engage young people are widespread and often highly successful across Wales, with many enthusiastic and energetic practitioners, a lot of activities and some splendid 'shop window' meetings and science festivals. These include, amongst

others, The Big Bang Wales, Wrexham Science Festival and the science pavilion at the National Eisteddfod. There is huge enthusiasm for STEM and interest and ability shown by young people and their teachers and educators. There is an issue to address however (also a widespread view in consultation) that this national pattern of activity requires greater coordination and leadership for it to be coherent and give effective coverage. Questions were also raised about the outcomes delivered by the various activities, further expressing a need for better direction setting and coordination.

We need to address a decline in GCSE take-up of STEM subjects, and the fact that take-up at A-level has not increased in line with overall A-level entries. In the five years to 2009/10 Welsh GCSE entries for STEM subjects by pupils aged 15 have declined by 12 per cent, 8 per cent more than the 4 per cent decline in the cohort, with a 15 per cent decline in the pure sciences. Whilst overall A-level entries have risen by 25 per cent, the increase is only 20 per cent in STEM subjects and 12 per cent in sciences. STEM AS-level entries have increased by 48 per cent, 5 per cent more than AS-level entries overall. In higher education, undergraduate STEM student enrolments in the six years to 2009/10 have risen by 15 per cent, similar to growth in total enrolments, with rises being particularly strong in biological sciences and mathematics. There are many contributory factors to the trends, from social and home circumstances, to strong variations by gender in subject choices.

The National Assembly for Wales' *The Report of the Enterprise and Learning*

*Committee on The Science, Technology, Engineering and Mathematics (STEM) Agenda*⁵⁵ highlighted a catalogue of issues – spanning the entire learning pathway, which need concerted action. Findings by Estyn, the education and training inspectorate for Wales, revealed ‘significantly lower’ standards in science and maths than other subjects. Research by the Royal Society showed the proportion of students in Wales taking biology, chemistry, physics and maths at A-level was significantly below the rest of the UK.⁵⁶ The reasons for these effects need to be carefully evaluated.

PISA (Programme for International Student Assessment)²⁸ aims to evaluate education systems worldwide by testing the ability of 15 year olds to apply skills and knowledge. Sixty five Organisation for Economic Cooperation and Development (OECD) member countries participated in PISA 2009. All four UK administrations participated. In PISA 2009, pupils in Wales achieved a mean score of 496 for science, not significantly different from the OECD average of 501, placing Wales in the middle ranks of achievement. In mathematics, Wales’ pupils achieved a mean score of 472, statistically lower than the OECD average of 496. For both science and mathematics the mean score for Wales was significantly lower than the other three parts of the UK. There is also a gender difference in Wales, with a significantly better performance by boys.⁵⁷ While a cautious approach is appropriate in terms of drawing conclusions based solely on PISA outcomes, these results do merit some concern for Wales.

5.2 Matching the supply of STEM-related skills to demand

The Minister for Education and Skills and Deputy Minister for Skills have published their intention to improve labour market intelligence. This will provide

the information needed by learners and education providers to better match the skills of young people to the demands of industry. The coordination and dissemination of this information, through more effective careers advice, will provide the information needed by learners to make informed choices on their futures, including the availability of careers in STEM-related disciplines. This information will be allied to the planning of apprenticeship and further education provision to ensure that state funded education is up to the challenge of securing the skills needed by the current and future STEM business community. The Welsh Government will also work with the higher education community to ensure that STEM pathways, from school to higher education, are available and meet the demands of the Welsh economy. Encouraging the participation of the private sector at all levels of education will be critical to the success of these measures.



A Science lesson at St. Cenydd School, Caerphilly.

5.3 The National Science Academy

The National Science Academy (NSA) is the Welsh Government’s main vehicle for encouraging greater participation in STEM. The academy will address the issue of STEM outreach, engaging students and increasing our workforce of scientists

and engineers. It was established in 2010 and will provide a structure for the leadership and organisation of the extensive network of STEM outreach activities that exists across Wales. It will be the NSA's role to bring national direction and coordination to STEM outreach activities, and the appointment of a coordinator is required.



'Blown Up' air fan exhibit at Techniquet, Cardiff Bay.

5.4 Actions: the promotion of STEM

Over the next year we will:

- develop our STEM strategy, building on a survey of existing activity, to engage and develop children and young people and increase the proportion of the cohort studying science and pursuing STEM-related careers, including more girls and women.
- set direction and coordinate outreach STEM activities through the NSA, including appointment of an NSA-STEM Coordinator.
- improve labour market intelligence to help shape informed career choices for young people, including market needs for STEM skills.

- examine ways to raise the standard of science and mathematics teaching from primary through to secondary education, including how improved or specialist teaching can be encouraged through recruitment and training (both initial and through Continuous Professional Development) to provide effective learning for all pupils, including those who want to study sciences as single A-levels.

Over the next five years we will:

- continue to target the supply of high quality graduates including through incentives into priority areas of STEM initial teacher training.
- continue to be committed to the provision of Continuous Professional Development for all STEM teachers and to working with partners in developing standards.
- develop and respond to research into progression in science education, including evidence relating to the study of two and three sciences at GCSE.
- ensure that our curricula for STEM subjects are in the vanguard of modern, challenging curricula for the students of Wales.



Year 8 Chemistry at Whitchurch High School, Cardiff.

6 Improving Delivery in Government

6.1 Strengthening leadership in science

In the Welsh Government, official level responsibility for science is distributed across the organisation and its agencies. This reflects the use of science in policy making, STEM skills enhancement, research base improvement and innovation promotion. Our structures help integrate science with programmes, but also pose challenges in executing a coherent strategy to improve performance.

We have already set out our commitment to stronger leadership in improving the research base and targeting strategic R&D opportunities. In terms of science advice, an informal review against the Government Office for Science's *Science and Engineering Assurance Framework*⁵⁸ has highlighted several areas of expertise that are well-connected with experts across the UK. The review also identified vulnerabilities in horizon scanning, influencing partners, planning to meet policy needs, quality assurance and resilience.



We are therefore setting up a new Chief Scientist's Department to lead this work across government. It will include both a Chief Scientific Officer leadership role

and a Chief Scientific Adviser advisory role. We will:

- bring the National Institute of Social Care and Health Research (NISCHR) under the direction of the Chief Scientific Adviser and reporting in turn to the Health and Social Care Department to maximise the opportunities to promote patient benefit, research and innovation capacity through health research.
- establish a new Science Division, as part of the new department, to lead efforts to improve the quality of research conducted in Wales, lead action to develop larger scale R&D proposals and raise the profile of science and engineering skills and careers.
- through the Science Division, lead improvement of science advice, working with colleagues across government to improve access to scientific evidence, promote good professional practice, inform policy through science-based futures evidence and agree priorities for developing our evidence.
- continue to support the Chief Scientific Adviser's role in providing independent advice across government, drawing on advice from the Science Advisory Council for Wales on science issues and from the new innovation leadership that emerges from the forthcoming innovation strategy, on innovation issues.

A longer term skills and succession plan aims to improve the internal science and engineering career structures, enhance skills in brokerage of science expertise and make more use of secondments in providing specialist science expertise.

6.2 Tracking and overseeing delivery

Our goal is to build a strong and dynamic science base that supports the economic and national development of Wales.

Principles which we will follow are set out in chapter 1, with actions and timescales identified in chapters 3-5.

This strategic document is agreed by Cabinet, and implementation and delivery plans will be overseen by an *ad hoc* group of Ministers chaired by the Minister for Business, Enterprise, Technology and Science, with Ministers for Education and Skills; Health and Social Services; and Environment and Sustainable Development – those Ministers who have the closest use of, and interest in, Welsh science. The Chief Scientific Adviser will report to Ministers on its implementation and advise on any further action needed to meet our goals. We will monitor progress in implementing our commitments and report internally to relevant boards and externally within the framework of the *Programme for Government*.

Our partners include:

- Higher Education Funding Council for Wales (HEFCW)
- Higher Education Wales (HEW) and the St David's Day group
- individual universities in Wales
- business sector panels
- The Learned Society of Wales
- STEM promotion organisations and partners
- schools and colleges
- UK funding agencies including Research Councils and the Technology Strategy Board

- the European Commission through structural funds
- NHS Wales

Progress monitoring will also track relevant measures, including:

- numbers participating in STEM engagement activities
- numbers of young people choosing to study STEM subjects
- trends in scale and volume of research applications and overall competitive funding
- development of expertise in research proposals and participation in research decision making
- trends in collaborative research with excellent groups
- trends in science publication and impact
- achievement of agreed metrics in EU-funded projects
- numbers of successful R&D projects with anchor and major companies
- numbers serving on UK Research Council's committees, boards and councils
- SME participation in, and feedback on, innovation programmes
- numbers of external scientific experts contributing evidence for policy and officials undertaking science related Continuous Professional Development.

And over a longer time frame:

- Wales' proportion of UK competitive research funding
- the percentage of Wales' research judged to be at the highest UK levels.

6.3 Outcomes

Success in building science and innovation is crucially important for our country. We must achieve more outcomes and deliverables, whether in pure science, applied science, innovation, industrial applications, national applications (health, environment, enterprise, energy). Success depends on many factors, trends and decisions. Not all are under the control of the Welsh Government. Our programme nevertheless seeks to make an impact on several long term outcomes. These include:

- economic – income and gross value added per capita, employment rate, quality of jobs, and inward investment by companies.
- educational – science achievement of young people (the percentage of pupils achieving core subject indicator English or Welsh first language, mathematics and science at Key Stage 2, age 11 and ranking in PISA). Student graduation with first-class or upper second class honours degrees, Masters and doctorates.
- health – gap in life expectancy between the most and least affluent.
- environment and sustainability – level of greenhouse gas emissions, percentage of habitats and species that are stable or improving, number of lakes, rivers and coastlines achieving good ecological status.
- science products – grant successes, inward investments, publications, citations, prizes/awards, patents and national prestige.
- innovation – evidence for translation of scientific results and output into innovation and commercialisation (patents, licenses, spin-out companies and market performance).

Appendix 1

Inaugural members of the Science Advisory Council for Wales

Name	Affiliation	Subject
Professor John Harries (Chair)	Welsh Government	Physics
Professor Chris Pollock (Independent Co-Chair)	Aberystwyth University	Agricultural research and policy
Paul Allen	Centre for Alternative Technology (CAT)	Energy and environment
Professor Huw Beynon	Wales Institute of Social & Economic Research, Data & Methods (WISERD)	Social sciences
Simon Bradley	EADS	Aerospace and defence
Kevin Bygate	Tata Steel UK	Industry and Innovation
Professor Bridget Emmett	Centre for Ecology & Hydrology (CEH)	Natural environment
Professor Sir Martin Evans	Cardiff University	Genetics/stem cells
Professor Chris Gaskell	Royal Agricultural College, Cirencester	Veterinary science, agri-food and land use
Professor Siân Hope	Bangor University	Computer science
Dr Jim Houlihan	Intellectual Property Office, Newport	Intellectual property
John Jeans	MRC Technology	Health science
Professor Tavi Murray	Swansea University	Geosciences/Glaciology
Professor Ole Petersen	Cardiff University	Biosciences
Wendy Sadler	Science Made Simple	Science communication
Professor Sir John Meurig Thomas	Cambridge University	Chemistry
Professor Ken Walters	Aberystwyth University	Mathematics
Professor Robin Williams	Swansea University	Physics

Appendix 2

Higher Education in Wales – numerical evidence

Table A2.1 RAE 2008 results for the UK as a whole and for the constituent countries

Quality level	% of Research Activity				
	Wales	England	Scotland	N Ireland	UK
4*	14	18	15	14	17
3*	35	37	37	36	37
2*	36	32	34	37	33
1*	14	11	13	12	11
u/c	1	1	2	1	1
4* + 3*	49	55	52	50	54

Source: 2008 Research Assessment Exercise: Outcomes for the Welsh Higher Education Sector, Higher Education Funding Council for Wales, 26 March 2009

Table A2.2 Wales' percentage of UK research Council grant income to universities by year

Year	96/ 97	97/ 98	98/ 99	99/ 00	00/ 01	01/ 02	02/ 03	03/ 04	04/ 05	05/ 06	06/ 07	07/ 08	08/ 09	09/ 10
Wales as a % of UK	2.8	2.9	3.1	3.2	3.3	3.4	3.4	3.4	3.1	3.2	3.1	3.2	3.4	3.3

Source: Higher Education Statistics (HESA) (Finance Statistics Record)

Table A2.3 (a) Research income of Higher Education Institutions in Wales, 2009/2010

	Total research Income £k	Recurrent Research Funding £k / %	Research Councils £k / %	UK charities £k / %	UK Central Gov't £k / %	UK industry, commerce £k / %	EU	Non-EU	Other
Glamorgan	6,855	3,353 49%	409 6%	205 3%	1,685 25%	206 3%	922 13%	2 0%	73 1%
Aberystwyth	27,524	7,959 29%	9,944 36%	737 3%	4,062 15%	1,475 5%	2,803 10%	413 2%	131 0%
Bangor	24,368	8,409 35%	5,301 22%	1,260 5%	5,467 22%	390 2%	2,784 11%	342 1%	415 2%
Cardiff	130,572	42,610 33%	27,080 21%	15,960 12%	26,530 20%	6,552 5%	6,698 5%	4,062 3%	1,080 1%
Trinity Saint David	1,240	996 80%	32 3%	1 0%	66 5%	145 12%	0 0%	0 0%	0 0%
Swansea	36,275	13,543 37%	9,298 26%	1,684 5%	5,725 16%	1,500 4%	3,637 10%	321 1%	567 2%
Cardiff Metropolitan	3,918	1,664 42%	235 6%	53 1%	1,497 38%	265 7%	203 5%	0 0%	1 0%
Newport	1,008	573 57%	189 19%	38 4%	68 7%	0 0%	140 14%	0 0%	0 0%
Glyndwr	2,655	338 13%	241 9%	19 1%	544 20%	449 17%	1,062 40%	2 0%	0 0%
Swansea Metropolitan	529	289 55%	24 5%	109 21%	62 12%	0 0%	0 0%	0 0%	45 9%
CAWCS*	788	363 46%	317 40%	33 4%	3 0%	48 6%	0 0%	0 0%	24 3%

* CAWCS is The Centre for Advanced Welsh and Celtic Studies within the University of Wales

Table A2.3 (b) Research income by UK constituent country, 2009/10

	Total research Income £k	Recurrent Research Funding £k / %	Research Councils £k / %	UK charities £k / %	UK Central Gov't £k / %	UK industry, commerce £k / %	EU	Non-EU	Other
Wales	235,732	80,097 33.98%	53,070 22.51%	20,099 8.53%	45,709 19.39%	11,030 4.68%	18,249 7.74%	5,142 2.18%	2,336 0.99%
Wales as % of UK	3.7%	4.1%	3.3%	2.2%	5.9%	3.9%	4.0%	1.8%	5.5%
England	5,081,724	1,582,636 31.14%	1,274,456 25.08%	756,762 14.89%	602,118 11.85%	217,961 4.29%	364,950 7.18%	254,231 5.00%	28,610 0.56%
England as % of UK	80.6%	80.9%	80.4%	82.5%	77.2%	77.9%	80.7%	88.0%	67.8%
Scotland	841,857	240,543 28.57%	234,044 27.80%	130,560 15.51%	100,386 11.92%	47,474 5.64%	57,698 6.85%	23,127 2.75%	8,025 0.95%
Scotland as % of UK	13.4%	12.3%	14.8%	14.2%	12.9%	17.0%	12.8%	8.0%	19.0%
N. Ireland	143,316	53,932 37.63%	23,787 16.60%	9,720 6.78%	31,350 21.87%	3,241 2.26%	11,608 8.10%	6,430 4.49%	3,248 2.27%
N.Ireland as % of UK	2.3%	2.8%	1.5%	1.1%	4.0%	1.2%	2.6%	2.2%	7.7%
Total UK	6,302,629	1,957,208 31.05%	1,585,357 25.15%	917,141 14.55%	779,563 12.37%	279,706 4.44%	452,505 7.18%	288,930 4.58%	42,219 0.67%

Sources: HESA Resources for Institutions of Higher Education 2009/10 (for all figures except Recurrent Research Funding). HEFCE, HEFCW and SHEFC Recurrent Grant Circulars, 2009/10 (for Recurrent Research Funding only). Note: Recurrent Research Funding consists of QR and PGR (or equivalent). All figures subject to rounding.

Table A2.4 Income and enrolment figures for Welsh universities in 2009/10

Institution	Income analysis – Welsh HEIs 2009/10				2009/10 enrolments from HESA			
	Total Research '£000	Total Teaching '£000	Total other '£000	Grand Total '£000	UG F/T	UG P/T	PG research	Total (all students incl. PGT)
Cardiff University	137,279	173,109	118,842	429,230	16,837	3,279	1,611	27,554
Swansea University	36,946	82,233	39,739	158,918	10,246	2,034	720	14,342
Bangor University	25,588	63,342	36,680	125,610	7,349	1,335	674	11,452
Aberystwyth University	27,656	53,220	39,887	120,763	6,839	2,191	333	10,806
University of Glamorgan	6,542	103,810	33,371	143,723	12,151	4,991	414	21,071
University of Wales, Lampeter	1,359	10,258	4,122	15,739	1,372	852	154	3,342
Trinity University College	0	10,106	6,226	16,332	1,277	1,272	0	2,764
Cardiff Metropolitan University	3,887	58,176	18,494	80,557	7,549	776	191	13,078
University of Wales, Newport	1,069	34,649	12,094	47,812	3,508	3,941	65	9,290
Glyndŵr University	2,845	30,804	9,859	43,508	3,060	3,805	108	8,002
Swansea Metropolitan University	548	29,914	6,609	37,071	3,561	1,347	81	6,185
University of Wales (central functions)	1,224	0	14,187	15,411	0	0	0	0
Open University in Wales	0	0	0	0	0	8,506	0	9,001
Total	244,943	649,621	340,110	1,234,674	73,749	34,329	4,351	136,887
UG Undergraduate PG Postgraduate F/T Full-time P/T Part-time PGT Postgraduate teaching								

Source: Higher Education Statistics Agency (HESA) student record, HESA finance statistics record as analysed by HEFCW

Appendix 3

An analysis of Wales' strengths in the three Grand Challenge priority areas

We have identified three Grand Challenge priorities where Wales has both excellent science and businesses that can exploit the outcome of research in these areas. What follows sets out some of the strengths in our universities, and other research institutions, and businesses within the given sector. We believe that these areas should be our focus as they are best placed to deliver the most value for Wales. The rationale is set out in section 3.4.

A3.1 Life sciences and health

The life sciences industry sector in Wales is worth more than £1.3 billion to the economy, generated by over 300 companies, employing over 15,000 people. When public sector and academic jobs and economic impact are factored in, these figures are considerably greater. Two thirds of these companies produce medical technologies and 93 per cent have fewer than 250 employees. The sector plays a key role in improving public health and reducing healthcare costs.⁵⁹



Wen Jiang, Professor of Surgery and Tumour Biology with Professor Keith Harding, Head of Wound Healing, both of Cardiff University

A future theme for this Grand Challenge area is: an excellent life sciences and health research foundation and an integrated health and social care database, supporting an innovative, evidence-based health and social care system for Wales, resulting in better patient outcomes and driving real business growth.



Printing of antibodies for next generation healthcare diagnostics – Swansea University.

Wales has significant assets in a devolved NHS, areas of health research excellence in a number of universities and strengths in the life sciences sector. Wales' success in the development of a single electronic patient record and the secure anonymised information linkage database make it an attractive location for medical trials and epidemiological work. There is an opportunity to raise impact by building better connections between the assets we already have.

Across the UK, research in life sciences and health is funded by the Research Councils and a range of commercial funders, charities and the four government health departments. The

Welsh Government funds health and social care research in Wales through the National Institute for Social Care and Health Research (NISCHR).⁶⁰ To energise and bolster the health and social care research landscape NISCHR's budget has increased in recent years to more than £43 million. This funding, in particular, seeks to create conditions to attract greater high quality funding from outside Wales. Also through NISCHR, NHS Wales has adopted some of the relevant recommendations from The Academy of Medical Sciences review⁶¹ to increase the speed and efficiency with which healthcare innovations become available to patients. Biomedical research centres and an Academic Health Sciences Collaboration have been set up to foster links between the NHS, higher education institutions and industry, and a research infrastructure to support trials and other well designed studies has been put in place. Although it is early days, there are encouraging signs of multiplier effects accumulating from NISCHR investment and leadership.

University strengths

There are many excellent life sciences and health research strengths in Welsh universities:

- Cardiff University has research strengths in a number of areas including neuroscience and mental health;⁶² psychology;⁶³ infection and immunity;⁶⁴ genetics;⁶⁵ cancer;⁶⁶ stem cells⁶⁷ and optometry & vision science.⁶⁸
- The Medical Research Council's Centre for Neuropsychiatric Genetics and Genomics at Cardiff University is the first UK facility dedicated to harnessing the genetics revolution for research into mental disorders.²³
- Scientists from the Cardiff School

of Pharmacy & Pharmaceutical Sciences⁶⁹ have discovered two potential anti-viral drugs for shingles and hepatitis C. The agents, developed in collaboration with US biopharmaceutical company Inhibitex, are demonstrating effectiveness in patients in ongoing clinical trials and underpin a peak NASDAQ market capitalisation of more than \$1.1 billion. Inhibitex has since been acquired by Bristol-Myers Squibb for \$2.5 billion, primarily due to the success of the hepatitis C drug.

- Swansea University's Institute of Life Science (ILS)⁷⁴ hosts the EPSRC National Mass Spectrometry Service Centre,⁷⁰ the Centre for NanoHealth,⁷¹ the e-health industries innovation (ehi2) centre,⁷² and the IBM 'Blue C' supercomputer – one of the fastest computers in the world dedicated to life sciences research.
- The Centre for the Development and Evaluation of Complex Interventions for Public Health Improvement (DECIPHER),⁷³ one of only five UK centres of public health research excellence, is a consortium between the universities of Cardiff, Bristol and Swansea, with an international reputation for excellence in the social sciences.
- Aberystwyth University's Institute of Biological, Environmental and Rural Sciences (IBERS)²⁴ is leading UK research studies in human nutrition. The Institute has been chosen to host the BBSRC National Plant Phenomics Centre, the lead facility in the UK for phenotyping. The Centre will independently screen traditionally bred and GM crops for a desirable chemical composition.
- Bangor University's School of Psychology⁷⁴ ranks among the very

best in the UK and forms a large part of the College of Health and Behavioural Sciences.⁷⁵

- The Centre for Applied Reconstructive Technologies in Surgery (CARTIS)⁷⁶ is a unique partnership that aims to make Wales a world-leader in the research, development and application of advanced technologies in surgery and prosthetics. The partnership combines the clinical expertise of Morriston Hospital's Maxillofacial Unit with the product design and development expertise of The National Centre for Product Design & Development Research (PDR)⁷⁷ at Cardiff Metropolitan University.

Business strengths

- Wales has a significant cluster of in vitro diagnostic companies, including global players Siemens Healthcare Diagnostics in the north and Ortho Clinical Diagnostics (a Johnson & Johnson company) in the south.
- Cardiff is home to GE Healthcare's international centre for Cell Technologies. The centre is undertaking groundbreaking R&D, commercialising and industrialising the growth and use of stem cells for drug discovery. The centre is also developing next generation cell therapy enabling technologies.
- The Wound Healing Research Unit at Cardiff University⁷⁸ is a pioneer of clinical, scientific and educational practice in the multi-faceted field of wound care. The Unit has a long track record of collaboration with commercial partners in the development of new products and treatments for wounds to benefit patients and healthcare providers.
- ConvaTec, a global leader in the development of innovative

wound dressings, has their Wound Therapeutics R&D operation and two manufacturing sites in Wales accounting for over 25 per cent of the company's global sales.

- PDR, a world renowned design and innovation consultancy and research centre, has significant experience in medical device development from simple disability devices and medical furniture through to complex diagnostic tools and drug delivery systems.
- Many small Welsh life sciences companies are actively investing in R&D and developing new products. During 2011, well over half the Welsh Government's RD&I proof of concept funding was claimed by the life sciences sector.

Growing the life sciences sector in Wales will deliver more than economic benefits. Having more and bigger businesses in Wales offers additional collaborative opportunities for universities and research partnerships, and will help create an ecosystem which encourages commercialisation. Businesses thrive by developing innovative technologies and therapies, demonstrating that they deliver improved patient outcomes, and bringing them quickly to market. All of these activities will deliver better healthcare and outcomes for patients in Wales.

A3.2 Low carbon, energy and environment

Businesses working on the energy programme and managing, monitoring and protecting the environment are an important cluster in Wales, and we have a range of well-regarded and highly-rated research teams active in low carbon, energy and environmental studies. Wales has over 40,000

people employed in the energy and environmental sectors, contributing more than £3.2 billion to the economy annually.⁷⁹

The Welsh Government has a near-unique statutory duty to establish a sustainable future in energy and the environment and has committed itself to a carbon emission reduction of three per cent per year.⁸⁰ It is also committed to climate change adaptation, as well as using high quality environmental and social science as the evidence base for policy development and environmental management in Wales.

The *Natural Environment Framework* is one of the major statements of policy principle by the Welsh Government in complying with our duty. It is about more effective governance of environmental resources in Wales within the context of sustainable development, which is our central organising principle.



Green Biotechnology – Aberystwyth University – Postgraduate student working with Miscanthus in one of IBERS' modern greenhouse facilities.

The health of ecosystems across Wales, and the services they provide, form a key element of our future approach to sustainable development in Wales. The UK National Ecosystem Assessment is an important evidence base for that approach.

The country provides a natural 'green' laboratory for many research studies to connect up in the future. A joined-up-thinking approach to low carbon, energy and the environment can be led by Wales.

A future theme for this Grand Challenge is: Wales as a green laboratory – with its businesses and academics working to test and demonstrate profitable technologies to achieve sustainable development.

Wales has a social, environmental and economic responsibility to provide leadership in low carbon energy generation, given the country's history in heavy industry and coal production, the major anthropogenic source for CO₂. Whole communities in Wales were established to service these industries, and the opportunity now exists for Wales to establish itself as a world leader in low carbon technology taking advantage of the strong skills and knowledge base, and our abundance of natural resources.

Wales has a wide range and depth of activities in the fields of low carbon, energy and environment. Thus, we see this to be a thematic area of exciting challenge and great strength for science in Wales.

The problems posed are not trivial. For example, we have to recognise an innate complexity in the Grand Challenge in this area, not least the conflicts that can arise between environmental issues and other priorities. Interrelated demands of energy production, food production and sustainable ecosystem management

often pull in different directions, e.g. some increasing carbon emissions, some decreasing them. Careful consideration needs to be given to the hierarchy of desired outcomes, and identification of activities which deliver maximum benefit with minimum adverse impact.

The evidence base is crucial, as is fostering international collaborations to deliver the research priorities identified by the Ministerial Advisory Group, and described in the Energy & Environment Sector Framework. The evidence must be objective, and it must be challenged and tested for accuracy in an open and traceable way. We envisage an integrated evidence base to promote integrated delivery, with scenarios extended beyond de-carbonisation to embrace sustainable ecosystem management and secure supply of energy.

University & institutional strengths



Dr Louise Jones at the Centre for Solar Energy Research, Glyndŵr University.

Wales' R&D capacity in this Grand Challenge area is considerable. Higher education in Wales has highly-rated research teams in the low carbon, climate change and environmental fields. The Low Carbon Research Institute (LCRI)¹³ unites and promotes energy research in Wales to help deliver a low carbon future. The multidisciplinary LCRI aims to support the energy sector in the UK

and globally, to develop low carbon generation, storage, distribution and end use technologies, and to offer policy advice. Engineering and manufacturing relevant to renewable energy generation are also studied, with particular strengths in photovoltaics,⁸¹ biocomposites,⁸² hydrogen fuel cells,⁸³ smart grid⁸⁴ and marine.⁸⁵

Significant deliverers of the knowledge base to help meet Wales' ambitious environmental targets are our centres of excellence across the country including:

- The Centre for Alternative Technology (CAT)⁸⁶ – the UK's leading education and visitor centre demonstrating practical solutions for sustainability
- The Centre for Solar Energy Research (CSER)⁸⁷ with proven expertise and a world-class reputation in researching novel photovoltaic materials and devices
- The Climate Change Consortium of Wales (C3W)³⁹ to understand the process and impact of climate change and to rationalise research activity throughout Wales for this agenda
- The Institute of Biological, Environmental and Rural Sciences (IBERS)²⁴ – a member of the BBSRC Sustainable Bioenergy Centre developing grasses as sources of sustainable biomass for bioenergy and biofuels
- BEACON: A Biorefining Centre of Excellence¹⁵
- The Centre for Integrated Research in the Rural Environment (CIRRE)⁸⁷
- The Centre for Catchment & Coastal Research⁸⁸
- Natural Environment Research Council's Centre for Ecology and Hydrology (CEH)²² researching the

impacts of air pollution, climate change and land use on ecosystem services

- The Wales Environment Research Hub (WERH)⁴⁰ coordinating environmental research in Wales to strengthen the evidence base for the Environment Strategy for Wales⁸⁹
- The Dyfi Biosphere project approved by the UN Educational, Scientific and Cultural organisation (UNESCO)⁹⁰
- The Gas Turbine Research Centre⁹¹ conducting research into gas turbine processes and efficiencies
- Welsh School of Architecture at Cardiff University,⁹² leading the UK in sustainable building design.



The First Minister of Wales officially launches SEACAMS on board the RV Prince Madog.

Business strengths

There are many key economic developments in Wales associated with low carbon energy production and the potential for that to drive a sustainable low carbon economy.

- The Sustainable Product Engineering Centre for Innovative Functional Industrial Coatings (SPECIFIC)⁹³ is an Innovation Knowledge Centre led by Swansea University and Tata Steel UK. SPECIFIC's primary aim is to transform buildings into 'power stations' through the rapid commercialisation of functional coatings on steel and glass in the areas of energy capture, storage and release. It is complemented by the Sustainable Building Envelope Centre (SBEC),⁹⁴ based at Tata Steel UK's Shotton site in north Wales. SBEC operates out of a specially refurbished building designed to act as a test rig and proving ground for new technologies, demonstrating them in use.
- SEACAMS⁹⁵ offering businesses in the marine and coastal sectors links to the knowledge base of the universities in Wales to promote innovation and expansion of the marine and coastal sector.
- The Anglesey Energy Island initiative aims to put Wales at the forefront of energy R&D, production and servicing, bringing with it significant economic rewards.
- G24i utilises the latest breakthrough in materials science and nanotechnology creating a new class of advanced solar cells which are the closest mankind has come to replicating nature's photosynthesis.
- Sharp has invested £26 million to establish its European headquarters for production of solar panels in Wrexham.
- Tidal Energy Ltd was recently successful in its planning application to site its tidal energy device within Ramsey Sound, Pembrokeshire. It has since been awarded £6.4 million from the European Regional Development Fund to make and install its DeltaStream device.
- Environmental consultancy is a growth sector in Wales with embedded scientific excellence which operates internationally, particularly in the areas of air pollution control

and land remediation.

The challenging targets set by the Welsh Government through policies such as *Towards Zero Waste*,⁹⁶ the *Climate Change Strategy* and major programmes such as Arbed to improve energy performance⁹⁷ are in themselves major drivers for scientific innovation and excellence in Wales. Taken together, these research-led activities and centres allow Wales to develop a major strength in integrated R&D to promote a sustainable future and drive the low carbon, low waste economy. Against this background we know there are significant evidence gaps across the spectrum of activities here which need closing. In addition, and equally vital, good data sets are a prerequisite to assessing government policy and monitoring the environment. These data sets can be produced by competent university researchers, private companies and government sources.

A3.3 Advanced engineering and materials



University of Glamorgan's Centre for Automotive Power System Engineering (CAPSE) – rolling road.

Industrially, Wales has a clear capability in small and medium scale engineering and materials production, which builds on our heritage of heavy engineering. Our universities have strengths in pure and applied research across a broad

range of topics, giving strong support to businesses through important industrial projects – in nanoengineering, aerospace, defence and automotive component production.

Universities and industry are involved in important sectors, including aerospace and defence and automotive technologies, building on underpinning capabilities in optoelectronics;⁹⁸ advanced materials and composites; hydrogen fuel technology; and process engineering. The statistics of this activity are dominated by aerospace and defence (290 companies, employing over 40,000 people, with a turnover in Wales of £5 billion annually),⁹⁹ automotive (200 companies employing 15,000 people with a turnover in Wales of £3 billion annually) and optoelectronics (over 5,000 employees and annual turnover in Wales of £1 billion annually).

A future theme is: developing innovations and technology for the 21st century, applied to challenges in environment, aerospace, manufacturing and materials.

University strengths

We have strong, world-leading university research in fields such as computational fluid dynamics; materials, particularly advanced testing methods; civil engineering; non-Newtonian fluid mechanics; printing and coating; low carbon technologies; nanotechnologies; astronomical spacecraft instrumentation and the production of state-of-the-art astronomical telescope mirrors.

Wales is leading in key areas in the development of alternative fuels in the UK, including hydrogen from renewable sources. The University of Glamorgan's Sustainable Environment Research Centre (SERC)¹⁰⁰ focuses on low carbon technologies and has an international

reputation in hydrogen research and development. The University is also the home of the advanced powertrain and battery research centre¹⁰¹ focused on applied research with industrial partners for electric and hydrogen vehicles. Cardiff University at the Gas Turbine Research Centre,⁹¹ are investigating novel gas mixes including hydrogen as a fuel in gas turbines.

The Welsh academic community is capable of delivering some of the strong science to underpin the automotive, optical and aerospace sectors; in functional coatings on steel, glass and plastics; in carbon fibre-based composite materials; in precision surfaces; and in software for engineering applications. Growth areas at the boundaries between advanced engineering and materials; energy and the environment; and life sciences offer exciting opportunities for innovation with new products and applications arising from these cross sector activities. To facilitate these activities, Welsh universities have entered into several collaborations, forming virtual institutes better suited to assisting their industrial partners.

Examples of strong, collaborative initiatives in this sector include:

- ASTUTE (Advanced Sustainable Manufacturing Technologies)¹⁰² a £26 million all-Wales project, led by Swansea University, to boost Wales' high-skills manufacturing sector. The project assists university collaboration with the aerospace, engineering and automotive industries to provide R&D support to produce more higher-value goods and services and bring them to a global market.
- Steels Training Research & Innovation Partnership (STRIP)¹⁰³ Swansea University has a world-class materials engineering department with a

long history of working with the metals and materials industries.¹⁰⁴

STRIP offers Welsh metals and manufacturing companies four year doctorate projects and one year masters research projects to help develop products or processes.

- Seren,¹⁰⁵ led by Cardiff University's Geoenvironmental Research Centre (GRC) in partnership with the British Geological Survey (BGS). Seren aims to build on geoenvironmental engineering research experience in Wales to develop innovative engineering technologies for commercial applications in geo-energy, such as ground source heat, underground coal gasification, carbon sequestration, and geoinformatic packages with low carbon applications.

Business strengths

Important large companies such as EADS (Airbus, Cassidian and EADS Innovation Works), Tata Steel UK, GE, General Dynamics, Dow Corning, BA, Sharp, Ford, Toyota, and IQE are central to the Welsh economy, recognised by their 'anchor' company status.¹⁰⁶ However, these anchors are large multinational companies and part of larger organisations usually headquartered outside Wales.

A large percentage of the industrial base in Wales is in small and medium sized companies. The *Manufacturing in Wales*¹⁰⁷ strategy says they must 'up their game', moving up the value added chain. This demands greater skills and better access to R&D. Few companies in this thematic area have strong R&D activity in Wales. More is needed from companies large and small, with exploitation of R&D from elsewhere if possible.

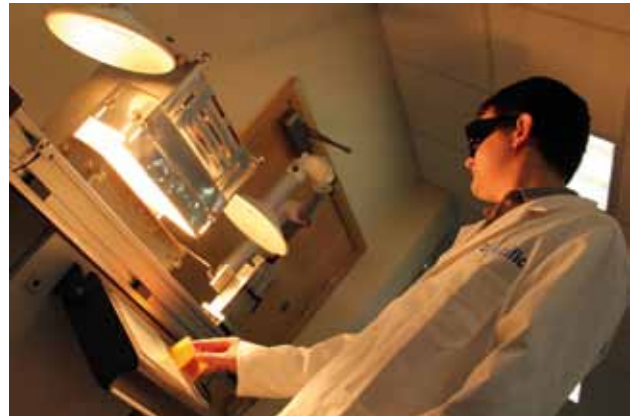


Accurate Robot drilling machine from Electroimpact based in Wales at Harwarden, Deeside.

SPECIFIC,⁹³ EADS Foundation Wales⁴, The Morgan-Botti Lightning Laboratory¹⁰⁸, TWI's IntACoM project¹⁰⁹ are outstanding examples of what can be achieved when business, universities and the Welsh Government work closely together under good leadership.

- SPECIFIC scales research excellence into commercially viable opportunities. As an equal industry and academic partnership, the initiative conceives, develops and accelerates ideas in functional, active coatings to deliver products with dynamic and sustainable properties, including energy generation. The project has created a world-class centre, based in Wales, where breakthrough technology will be scaled up. This should result in the creation of a new manufacturing stream to create new materials bringing a wide range of sustainable

solutions, such as low carbon energy generation and storage in buildings. These will help reduce carbon dioxide emissions as well as encourage economic growth.



Using a near infrared oven in one of the SPECIFIC labs. © Tata Steel UK.

- EADS has partnered with the Welsh Government and Cardiff University in setting up the not-for-profit limited company EADS Foundation Wales to take forward research and technology projects. The Foundation, the first of its kind in the UK, funds new R&D ideas emerging from the SME community and university sector.
- EADS Innovation Works has joined forces with the Cardiff School of Engineering's High Voltage Energy Systems research group to establish the Morgan-Botti Lightning Laboratory. Research into the effects of lightning strikes on aircraft composite materials and structures is the main focus of the laboratory. The research centre, created with £1.6 million in joint funding by the Welsh Government and EADS Innovation Works, is the most advanced university-based lightning test facility in the UK. Ultimately, the research aims to contribute to the development of more environmentally-friendly and safer aircraft.

- TWI, a global leader in technology engineering with a base in Port Talbot, is leading on a project called IntACoM (Improving the Inspectability of Aerospace Composite Materials) that will speed up the inspection process of composite materials used to build aircraft by 400 per cent. The project is co-funded by Welsh Government and industrial collaboration partners Rolls Royce, Bombardier and GKN. The project also brings in expertise from Swansea and Swansea Metropolitan universities.

processes. Higher education institutions and their external advisory committees must ensure courses are relevant and timely.

Companies say they value undergraduate placements (GO Wales), knowledge transfer partnerships (KTPs) and engineering doctorates that link business needs to university research. One-year Masters' courses and shorter continuing professional development courses present flexible and rapid routes to learn new technologies.

There are a number of science outreach activities and presentational installations around Wales aimed at schools or the public. Examples are the Sustainable Building Envelope Centre (SBEC) at Shotton, SPECIFIC in Baglan, Sharp in St Asaph and Cassidian in Newport. These are excellent examples of industry becoming well integrated with local communities and demonstrating the high skill jobs and rewarding careers available in science and industry.

The Advanced Composite Training and Development Centre in Broughton¹¹⁰ helps thousands of Airbus UK apprentices and employees develop and improve their composite manufacturing skills. The Centre is partially funded by the Welsh Government with Glyndŵr University providing higher education courses focusing on research and Deeside College providing further education courses.

Quality people at all levels are the key to success. Good work-based learning and apprentice schemes must be built upon. Foundation degrees offer new opportunities. Wales needs well trained and lateral-thinking graduates who can work in teams – especially those graduates with a sound grasp of core science disciplines, to engage with constantly changing technologies and

References

1. <http://wales.gov.uk/about/programmeforgovernment/?lang=en>
2. The Scientific Century: securing our future prosperity, The Royal Society, March 2010 <http://royalsociety.org/policy/publications/2010/scientific-century/>
3. www.hefce.ac.uk/research/ref/
4. <http://eadsfoundation.com>
5. 2008 Research Assessment Exercise: Outcomes for the Welsh Higher Education Sector, 26 March 2009, Ref W09/07HE, HEFCW
6. *Benchmarking University Research in Wales*, Professor Peter Halligan, analysis by Elsevier for St David's Day Group, 2011. See also: *International Comparative Performance of the UK Research Base – 2011*, Elsevier, for Department of Innovation Business and Skills, 2011, Figures 4.6, 4.8, 4.10
7. Science, Engineering & the Devolved Nations, CASE Policy Report Number 11, April 2011 www.sciencecampaign.org.uk/documents/2011/ScienceEngineering&DevolvedRegions2011.pdf
8. www.timeshighereducation.co.uk/world-university-rankings/
9. Report of Research, Innovation and Engagement Committee's Research Sub-Group HEFCW/11/07 www.hefcw.ac.uk/council_and_committees/council_papers_and_minutes/2011/council_papers_minutes_2011_27_january.aspx – agenda item 11
10. www.ons.gov.uk/ons/rel/rdit1/bus-ent-res-and-dev/2010/index.html
11. <http://wales.gov.uk/topics/educationandskills/publications/reports/researchreviewplan/?lang=en>
12. www.hefcw.ac.uk/documents/council_and_committees/committees/RIEC/Research%20Sub-Group%20Report.pdf
13. Low Carbon Research Institute (LCRI) www.lcri.org.uk
14. www.swan.ac.uk/ils
15. www.beaconwales.org/
16. Evidence from Minister for Business, Enterprise, Technology and Science to the National Assembly for Wales' Enterprise and Business Committee on 22 September 2011
www.senedd.assemblywales.org/documents/s2456/EBC4-02-11%20Paper%203%20-%20Evidence%20from%20Edwina%20Hart,%20Minister%20for%20Business,%20Enterprise,%20Technology%20and%20Science%20E.html?CT=2
17. Welsh Assembly Government's *Economic Renewal: a new direction*, July 2010, <http://wales.gov.uk/docs/det/report/100705anewdirectionen.pdf>
18. First Minister, Rt. Hon Carwyn Jones AM, lead article in *Talent: Welsh engineering talent for the future*, (no.14, September 2010)
<http://www.thefreelibrary.com/Making+Wales+a+learning+country.-a0236601091>
19. Both the Gates Foundation and the United States Government's National Institutes of Health (NIH) deploy research funding in the UK. There are examples from other non-EU nations as well as programmes such as the UK-India Education and Research Initiative.

20. *The Future Shape of Higher Education in Wales*: In March 2011, the Minister for Education and Skills asked the Higher Education Funding Council for Wales (HEFCW) to provide him with advice on the structure of the higher education sector in Wales. In June, the Council submitted its report, which sets out very clear recommendations for the future of the sector.
<http://wales.gov.uk/consultations/education/heinwales/?jsessionid=DHTYT1yNM9N5WSTBpsXQGhBXRScGvgbvH1xKZ0JLMgj1543TG1vw!-1206084875?lang=en>
21. *Achievement and Accountability: The Report of the Independent Review of Higher Education Governance in Wales* March 2011 <http://wales.gov.uk/docs/dcells/publications/110317hegovreviewen.pdf>
22. www.ceh.ac.uk
23. <http://medicine.cf.ac.uk/research/research-groups/cngg/>
24. <http://www.aber.ac.uk/en/ibers/>
25. Many great breakthroughs which have transformed the way we live have come from undirected, curiosity driven research such as antibiotics, the laser, nuclear fission, optical fibres, optoelectronics, polymers, the transistor, DNA & genomics and magnetic resonance imaging.
26. CBI Wales represents the country's biggest employers, including 75% of anchor companies and a range of growth SMEs. It is the main business organisation working with the Welsh Government to deliver a more competitive business environment. www.cbi.org.uk/about-the-cbi/uk/wales/. <http://learnedsocietywales.ac.uk/node/253> details a speech to The Learned Society of Wales, delivered by Mr David Rosser, Director CBI Wales on 18.5.2011 where he makes this point, at p.53, paragraphs 5 and 6.
27. Pooling – the process, adopted in Scotland, for bringing pan-national subject areas together to work cooperatively on major research projects www.sfc.ac.uk/research/researchpools/researchpools.aspx
28. OECD Programme for International Student Assessment (PISA) www.pisa.oecd.org Note there are a number of factors that can affect PISA results, so caution is required when calling them in evidence.
29. For example, see Prof Richard Davies 'The focus is on collaboration as universities get EU cash for R&D...' Western Mail, 20 July 2011
www.thefreelibrary.com/The+focus+is+on+collaboration+as+universities+get+EU+cash+for+R%26D%3B...-a0261812323 An example of a good move in this direction is the Low Carbon Research Institute (LCRI) www.lcri.org.uk
30. The Russell Group represents 20 leading UK universities which are committed to maintaining the very best research, an outstanding teaching and learning experience and unrivalled links with business and the public sector
www.russellgroup.ac.uk
31. Higher Education – Business and Community Interaction Survey 2009-10
www.hefce.ac.uk/pubs/hefce/2011/11_25/
www.hefcw.ac.uk/about_he_in_wales/statistics/business_communities_survey_hebcis.aspx
32. Note that the University of Glamorgan has a much smaller research portfolio than the other four universities in the St David's Day Group – see Appendix 2

33. For example, Vitae is the UK organisation championing the personal, professional and career development of doctoral researchers and research staff in higher education www.vitae.ac.uk
34. HEFCW is a signatory to and joint funder of the *Concordat to Support the Career Development of Researchers* that provides a single unambiguous statement of the expectations and responsibilities of researchers, their managers, employers and funders in relation to career development, and aims to increase the attractiveness and sustainability of research careers in the UK. Linked to their progress in implementing this Concordat, Cardiff, Swansea and Aberystwyth Universities have recently been awarded the European 'HR Excellence in Research' badge.
35. Example given in private communication from HEFCW.
36. www.sfi.ie and www.djei.ie/publications/science/2008/value_for_money_review_sfi.pdf. The views of Professor Chris Dainty, ex-Imperial College, London, now National University of Ireland, Galway (Optics), shared with the Chief Scientific Adviser for Wales, were also very positive.
37. The Wales Institute of Mathematical and Computational Sciences (WIMCS) www.wimcs.ac.uk
38. University of Wales Institute of non-Newtonian Fluid Mechanics www.wales.ac.uk/en/AboutUs/LinkswithOtherOrganisations/OtherUniversityBodies/Instituteofnon-NewtonianFluidMechanics.aspx
39. www.climatechangewales.ac.uk
40. www.werh.org/
41. www.nesta.org.uk/areas_of_work/economic_growth/the_innovation_index/assets/features/annual_innovation_report
42. http://ec.europa.eu/research/innovation-union/index_en.cfm?pg=keydocs
43. <http://www.bis.gov.uk/innovatingforgrowth>
44. www.technium.co.uk
45. <http://www.glyndwr.ac.uk/enOurcampusesandfacilitiesGlyndwrUniversityStAsaph/>
<http://www.opticinnovations.co.uk/>
46. *Strategic Skills Assessment for the Digital Economy 2010* www.skillset.org/uploads/pdf/asset_14618.pdf?1
47. BIS Economics Paper No.8, *UK trade performance: Patterns in UK and global trade growth*, November 2010 www.bis.gov.uk/assets/biscore/economics-and-statistics/docs/u/10-803-uk-trade-performance-growth-patterns
48. <http://wales.gov.uk/topics/businessandconomy/digitalwales>
49. Dr. Robert Pitkethly presented the findings from the second UK Intellectual Property Awareness Survey 2010, Intellectual Property Office, May 2010 www.ipo.gov.uk/ipsurvey2010.pdf
First findings from the UK Innovation Survey 2007, Economic & Labour Market Review, Vol 2, No 4, April 2008, Stephanie Robson and Greg Haigh, Department for Innovation, Universities and Skills www.bis.gov.uk/assets/biscore/corporate/migratedd/publications/e/elmr_apr08_robson.pdf
50. http://www.hm-treasury.gov.uk/lambert_review_business_university_collab.htm

51. http://ec.europa.eu/invest-in-research/pdf/ip_recommendation_en.pdf.
52. <http://www.bis.gov.uk/he-debate-wellings>.
53. *Digital Opportunity – A Review of Intellectual Property and Growth*, an independent report by Professor Ian Hargreaves, May 2011 www.ipo.gov.uk/ipreview-finalreport.pdf
54. BIS Research Paper Number 30, *STEM Graduates in Non STEM Jobs*, March 2011 www.bis.gov.uk/assets/biscore/further-education-skills/docs/s/11-771-stem-graduates-in-non-stem-jobs.pdf
55. http://www.assemblywales.org/stem_agenda_report-e.pdf
56. The Royal Society, *State of the nation, Preparing for the transfer to STEM higher education*, 15 February 2011 <http://royalsociety.org/education/policy/state-of-nation/higher-education/>
57. Bradshaw, J., Ager, R., Burge, B. and Wheeler, R. (2010). *PISA 2009: Achievement of 15-Year-Olds in Wales*. Slough: NFER. www.nfer.ac.uk/nfer/publications/NPDZ02/NPDZ02.pdf
58. www.bis.gov.uk/go-science/science-in-government/reviewing-science-and-engineering/review-framework
59. www.mediawales.com
60. www.nischr.org.uk
61. The Academy of Medical Sciences review, '*A new pathway for the regulation and governance of health research*', January 2011 www.acmedsci.ac.uk/index.php?pid=47&prid=88
62. www.cardiff.ac.uk/research/neuroscience
63. <http://psych.cf.ac.uk/research>
64. <http://medicine.cf.ac.uk/en/infect-immun/>
65. <http://medicine.cf.ac.uk/en/cancer-genetics/medical-genetics/>
66. <http://medicine.cf.ac.uk/en/cancer-genetics/research/>
67. www.cardiff.ac.uk/research/cancerstemcell
68. www.cardiff.ac.uk/optom/research/
69. www.cardiff.ac.uk/phrmy/contactsandpeople/fulltimeacademicstaff/mcguigan-chrisnew-overview_new.html
70. <http://www.swan.ac.uk/medicine/instituteofmassspectrometry/epsrnmssc/>
71. <http://www.swan.ac.uk/nanohealth/>
72. www.ehi2.swansea.ac.uk
73. www.decipher.uk.net
74. www.bangor.ac.uk/psychology/
75. www.bangor.ac.uk/cohabs/
76. www.cartis.org/
77. <http://pdronline.info/>
78. <http://www.cf.ac.uk/focuson/woundhealingresearchunit/index.html>
79. *Low Carbon and Environmental Goods and Services: An Industry Analysis*, Innovas Solutions Ltd, 2009 <http://www.bis.gov.uk/files/file50254.pdf>
80. *The Welsh Government's Climate Change Strategy for Wales*, October 2010

<http://wales.gov.uk/topics/environmentcountryside/climatechange/tacklingchange/strategy/walesstrategy/?lang=en>

81. www.cser.org.uk/
82. www.bc.bangor.ac.uk
83. <http://hydrogen.research.glam.ac.uk/centre/>
84. www.engin.cf.ac.uk/research/resInstitute.asp?InstNo=9
85. www.swan.ac.uk/engineering/marineenergy/
86. www.cat.org.uk/
87. www.cirre.ac.uk/
88. www.cccr.ac.uk/
89. <http://wales.gov.uk/topics/environmentcountryside/epq/envstratforwales/?lang=en>
90. www.dyfibiosphere.org.uk/
91. www.cu-gtrc.co.uk/
92. www.cardiff.ac.uk/archi/
93. www.swan.ac.uk/engineering/specific/
94. www.sbec.eu.com/en/
95. www.seacams.ac.uk/
96. http://wales.gov.uk/topics/environmentcountryside/epq/waste_recycling/publication/towardszero/?lang=en
97. <http://wales.gov.uk/topics/environmentcountryside/energy/efficiency/arbed/?lang=en>
98. <https://www.expertisewales.com/university-of-glamorgan/optoelectronic-innovation-and-commercialisation-centre-oic#>
99. Deloitte: *A guide to investing in Wales*, appendix 1: key sectors, March 2011
http://issuu.com/davelongfdi/docs/guide_to_investing_in_wales
100. <http://serc.research.glam.ac.uk/>
101. <http://fat.glam.ac.uk/consultancy/CEREA/>
102. www.astutewales.com/en/
103. www.swan.ac.uk/engineering/research/strip/
104. www.swan.ac.uk/engineering/materials/
105. <http://grc.engineering.cf.ac.uk/seren/>
106. An anchor company is a global or international organisation with headquarters or significant corporate presence in Wales.
107. www.eef.org.uk/publications/reports/Manufacturing-in-Wales.htm
108. <http://www.cf.ac.uk/news/articles/lightning-research-advances-7430.html>
109. www.twiprofessional.com/content/c1701.html
110. <http://www.glyndwr.ac.uk/en/Ourcampusesandfacilities/AdvancedCompositeTrainingandDevelopmentCentre>

Notes

This image shows a single sheet of white paper with horizontal blue ruling lines. The lines are evenly spaced and run across the width of the page. There are no margins, text, or other markings on the paper.

Notes

[illegible]