

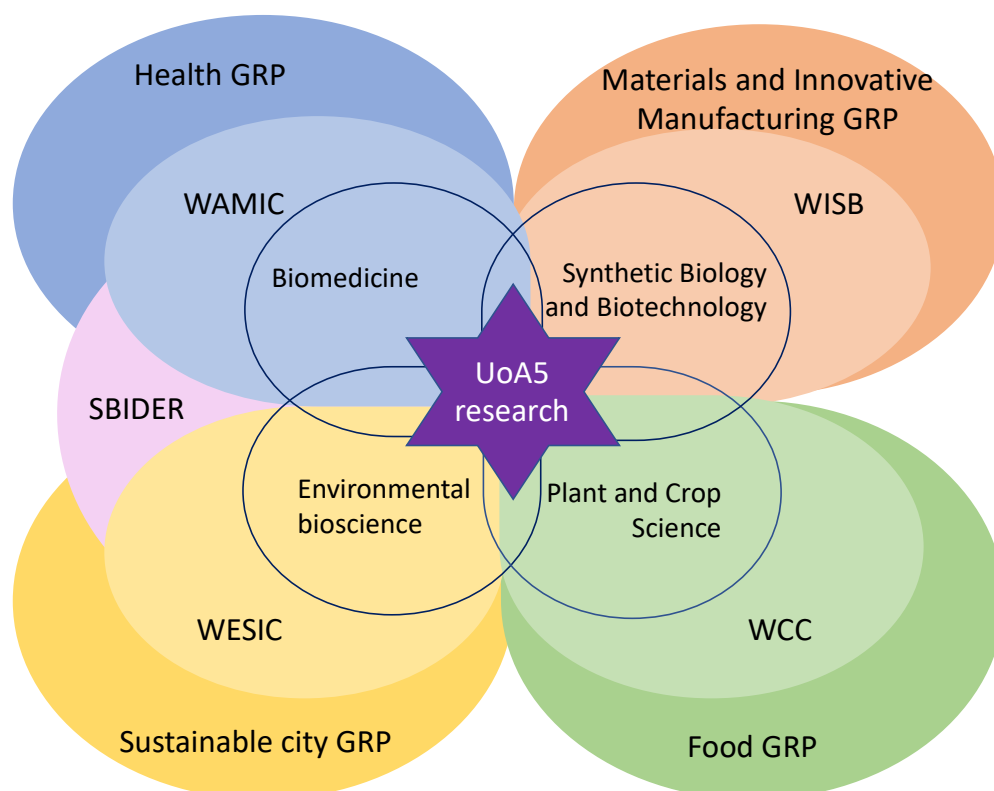
Institution: University of Warwick
Unit of Assessment: A5 Biological Sciences
<p>1. Unit context and structure, research and impact strategy</p> <p>The School of Life Sciences (SLS) supports exciting, highly interdisciplinary bioscience research, ranging in scale from molecules, through cells and organisms to synthetic populations and global ecosystems, and spanning viruses, bacteria, protists, fungi, animals and plants. Studying this diversity allows us to operate across the breadth of living systems and investigate solutions to major global challenges.</p> <p>We have a cohesive, enthusiastic community producing world-class, high-impact research within an ambitious, vibrant yet nurturing and highly collaborative research environment. The atmosphere in the School is open, friendly and most importantly, inclusive. Our reach will be significantly enhanced by the opening in February 2021 of our new, £54m state-of-the-art Interdisciplinary Biomedical Research Building (IBRB) (REF5a-4.2). A flagship science building for the University, the IBRB will facilitate strategic, collaborative working between SLS and Warwick Medical School (WMS) providing premium research space to grow our world-leading STEMM research and innovate in the strategic areas of neurobiology, infection biology and cell and tissue models for disease.</p> <p>Our core strengths encompass the use of modern analytical technologies to understand how molecular and cellular mechanisms control function at different scales. Our outputs are diverse, with demonstrable impacts in medicine, the bioeconomy and agriculture, all addressing the overall University mission of Excellence with Purpose (REF5a-1.2, 2.1).</p> <p>SLS currently has 62 academic research and teaching FTE and 11 teaching focussed FTE, with support from 31 administrative and 38 technical support FTE. Our strategy organizes our research strengths into four research themes: Biomedical Sciences, Environmental Science, Biotechnology and Synthetic Biology, and Plant and Crop Science, with the majority of our staff being active members of two or more of the themes, reflecting our strong inter-disciplinary, outward facing culture. Themes are further strengthened by interdepartmental links, including joint appointments, interdisciplinary research centres and the University Global Research Priorities (GRPs) initiative (REF5a-2.9.1).</p> <p>Overarching research strategy</p> <p>The School's strategy since REF2014 has focussed on developing a strong community of interdisciplinary researchers, maximising interactions between work at the Gibbet Hill and Wellesbourne campuses. This strategy has led successfully to this submission to a single UoA in REF2021. SLS is within the top 15 UK biology departments for research income/FTE (around £200K per academic FTE), but the School's size has been significantly smaller than that of most of its direct competitors. Therefore, in 2017, following a robust internal process, we launched our ten-year strategy. Developed in consultation with our own community and with the support of the University, it includes a vision to grow staff and student numbers in order to: foster a culture of innovative cross-disciplinary research that will underpin key national and global issues such as ageing, antimicrobial resistance, environment and food security; build research capacity, quality, income and impact in chosen areas of research; and train the next generation of scientists and technologists by continuing to deliver an outstanding student experience through a research-led, internationally competitive portfolio of degrees.</p>

Specifically, our strategy includes a planned investment in several new posts including 19 R&T, 5 TF plus 9.5 support staff FTEs. The first recruitment phase (2018-20) is now complete, with 7 new academic appointments (6 new posts and 1 replacement) and 2 pending (as of Dec 2020): Prof Boltze (Neuroscience), Prof Bassel (Computational Biology), Dr Stansfeld (joint with Chemistry), Dr Sagona (Associate Prof of Infection/Structural Biology), Dr Mushinski and Dr Puxty (Assistant Professors of Environmental Biology), and Dr Martins (Assistant Prof, Computational Biology).

In order to keep our strategy fresh, relevant and inclusive, we formed the Research Strategy Committee, which is chaired by the Head of School (HoS) and comprises the Director of Research, research leaders, Deputy Head of School, Head of Administration, Research Strategy Development Officer (RSDO) and Research & Impact Services (R&IS) (REF5a-1.7). It oversees high-level decisions on research strategy and develops and implements policies designed to promote research and impact excellence. A separate Research Management Committee reviews progress against strategy, safe working practices, training, industry liaison and funding opportunities. It is chaired by the Director of Research and is attended by the Research Theme leads, RSDO, and chair of Health and Safety.

Our four Research Themes shape our research culture and work synergistically with interdisciplinary Research Centres and the University's Global Research Priorities, as shown in the figure below:

Research Themes, Centres and GRP



Research themes

Biomedical science: the research vision for this theme is to capitalise on ever greater integration with colleagues in WMS (REF5a-2.7), bolstered by co-location in the new building, to understand and exploit key mechanisms enabling a healthy brain and a healthy body.

The theme is delivering **world-class fundamental research on basic biological processes which is fuelling translational medicine approaches**. Theme members investigate the

molecular basis of host-pathogen interactions and anti-microbial resistance; neuronal communication and neurodegenerative diseases and models of transmission and control of infectious diseases. Highlights include: Prof Keeling and the SBIDER team of epidemiologists are advising SAGE on the frontline of the national COVID-19 response strategy; Dr Connelly won a UKRI Future Leaders Fellowship for the development of new antimicrobials based on ancient textbook recipes; Prof Dowson won £1.1M from MRC for developing China-UK AMR hubs, funding for drug candidate screening through the Biomedicines Catapult and has set up a spinout company which provides a drug candidate screening service; pioneering studies on influenza virus and pneumovirus by Prof Easton led to the development of a vaccination strategy based on non-infectious, interfering viral particles and his spinout company (Virion Health) secured in excess of £20M for further development and phase II trials. Our neurobiology group is led by Prof Dale who has an international reputation for the study of nutrient/CO₂ sensing and the development and use of biosensors to investigate neuronal signalling. The world's first point-of-care biosensors for the early diagnosis of stroke are being commercialised by his spinout company Sarissa Biomedical Ltd which has received £6.9M investment since 2013. The appointment of Prof Boltze, a world expert in stroke and vascular dementia, adds depth to this vibrant research community, which also benefits from extensive interactions with clinicians and engineers.

Biotechnology and synthetic biology: The research vision for this theme is to promote bio-businesses through informed and directed innovation. Three young spinout companies are examples of this drive: Humane Technologies (est. 2017, Prof Soyer) which designs and produces measurement devices and associated data collection platforms for biotechnology; Cytecom (est. 2018, Dr Asally) which offers ultra-fast technology to detect bacteria in complex environments; Lucidix Biolabs Ltd (Est 2017, Dr Sagona) for bacteriophage-based diagnostics for the detection of bacterial infections in medical and food samples.

This theme is focussing on **engineering biosystems for a stronger bioeconomy**. The theme uses 'omics and synthetic biology to understand cell differentiation, community structure, stochasticity, metabolite cycling, crop performance under stress, and use *in silico* evolution to understand and develop biological products. Highlights include the BBSRC/EPSRC-funded WISB Centre for synthetic biology (£10.5M, McCarthy) which supports multidisciplinary science for new bioengineering technologies, processes and products. Dr Asally's work on electrical signalling and bacterial biofilms is setting a new paradigm for the detection of pathogens in fluids. Dr Corre is engineering biosynthetic pathways to generate complex natural bioactive compounds in microorganisms such as *Streptomyces*. Prof Soyer is designing synthetic microbial communities of defined species which collectively provide catalytic activities of industrial value. Dr Ntoukakis and colleagues are evaluating synthetic effectors (synEffectors) for re-engineering signalling pathways in plants to enhance stress resilience. Prof McCarthy (WISB Director), Dr Jaramillo, Dr Carpenter and Dr Hebenstreit are developing new synthetic prokaryotic and eukaryotic biomolecular circuitry with computational tools for understanding and predicting process control. Successes include a UKRI Future Leaders Fellowship to Dr Carpenter to develop his work with mini-GCPRs as synthetic switches, and an EPSRC/BBSRC award to Dr Hebenstreit (£2M, with colleagues from Physics and Mathematics) for defining transcriptional phase transitions.

Environmental biosciences: The research vision for this theme is to study global resource cycles and deliver strategies and policies for sustainable management of natural environments, from the microbiome to global ecosystems.

Meeting the challenges of a dynamic planet is at the heart of this theme's research strategy. We have world leading experts in marine and environmental microbiomes (Prof Scanlan, Prof

Bending, Prof Chen) and metagenomics (Prof Bending, Prof Wellington, Prof Allaby), arctic research (Dr Schafer) and climate active gases (Dr Purdy). Scientific highlights include the discovery of structural photosynthetic adaptations of the marine phototroph *Prochlorococcus* that allow it to adapt to different ecological niches (Scanlan, Nature Plants 2019, recently awarded a £2.3M ERC Advanced Investigator grant). Prof Wellington leads an international team using metagenomics to study environmental reservoirs of pathogenic bacteria in soil and water, and native wild animals, including badgers as hosts for bovine TB. She also leads the Warwick Environmental Systems Interdisciplinary Centre (WESIC), a cross-campus initiative that focusses on understanding how environmental changes affect biological communities. Prof Chen holds an ERC consolidator award (£1.8M) as well as funding from The Leverhulme Trust, The Royal Society and NERC. His work on microbial diversity and the metabolism of methylamines, quaternary amines and lipids links the microbiomes of the human body to terrestrial and marine ecosystems. Prof Bending has awards from BBSRC and NERC to help explain the complexity of root zone microbiomes and their contributions to natural mineral cycles and yield. Prof Allaby develops novel tools to study plant evolutionary genetics, plant domestication and archaeobotany. His techniques for analysis of ancient DNA have led to publications in Nature Plants 2019 (on the domestication of Sorghum) and Science 2018 (on the evolutionary legacy of maize in South America) and have also been adopted for bat identification by genotyping by his spinout company Ecological Forensics, which serves more than 800 customers.

Plant and crop sciences: The research vision for this theme is to tackle questions at the heart of plant health and productivity, and **transform crop improvement and protection strategies**, with a particular focus on SLS's research strengths in vegetable crops.

Research in this theme spans fundamental plant biology through to translational science and exploits our unique resources at the Warwick Crop Centre (WCC). Highlights include Prof Grant's work on the genome sequence and metabolic diversity of European ash trees (Nature, 2017) to the deployment by Syngenta of a gene that confers natural, broad-spectrum resistance to Turnip Mosaic Virus in commercial varieties of Chinese cabbage (Prof Walsh). Prof Gutierrez-Marcos showed that there is partial maintenance of organ-specific epigenetic marks during plant asexual reproduction (PNAS, 2018): his work explains important heritable phenotypic variation relevant to the propagation of many horticultural crops (BBSRC-NSF award, 2019). Prof Napier's research on auxin perception was funded by Corteva Agriscience (£0.6M) and helped launch two new auxin herbicides globally, Arylex Active for cereals and Rinskor Active for rice. Dr Barker and WCC scientists run the Defra-funded national vegetable genetic improvement network (VeGIN, £0.88M). VeGIN is allied to the UK Vegetable Gene Bank (£0.5M), hosted by SLS at Wellesbourne, which has provided germplasm to 200 academic and commercial breeding groups across the world. Prof Holub has revived elite *Phaseolus* material from the Gene Bank and has recently bred and registered the first haricot bean varieties suited to the UK climate. These add arable rotation options for farmers and have received widespread press coverage and industrial interest. In recognition of the strength in translational crop science at Warwick, an endowment from The Elizabeth Creak Charitable Trust (ECCT) of £5M created a Chair of Food Security which is held by Prof Grant. The ECCT and a bequest from the Brewster family have contributed £1.75M to a Centre for Horticultural Technology focussing on crop gene editing, which opened in Autumn 2020. Prof Grant and Dr Ntoukakis lead a £2 million project on *Xanthomonas* diseases in the UK in partnership with Exeter University and Fera.

Interdisciplinary research

Interdisciplinarity has become embedded in all our activities. Since REF 2014 SLS has played a key role in establishing cross-faculty interdisciplinary centres, including Warwick Antimicrobial Interdisciplinary Centre (WAMIC, Chair Prof Keeling), Warwick Environmental Sciences Interdisciplinary Centre (WESIC, Directors Prof Wellington and Prof Allaby), WISB (Director Prof McCarthy), the Epidemiology Research centre SBIDER which is directed by Prof Keeling, and the Warwick Centre for Industrial Biotechnology and Biorefining (WCIBB) involving Dr Corre, Dr Schäfer and Dr Barker amongst others. The School contributes to many of the University's Global Research Priorities (GRP): Materials and Innovative Manufacturing (co-Director, Dr Barker), Food (co-Director, Prof Collier) and Health (Prof Dowson as AMR lead) (REF5a-2.9.1).

Impact strategy

We have a strong record of achievement in embedding translational research in our culture and practices. We foster partnerships and our researchers benefit from a targeted programme of support. The School-based research and impact team provides a bespoke, one-to-one service for MTAs, NDAs and contract development. Warwick Innovations (REF5a-2.8) runs weekly consultations on IP protection and exploitations. A regular pump-priming competition offers vouchers for initiating projects with industrial partners, with awards available to all staff. SLS also makes regular use of institutional awards, such as the BBSRC Impact Acceleration Account (REF5a-2.7) and Innovate UK KTPs. Outputs from both of these are represented in our impact case studies. Research themes work together to organise industry-partnering days, research development workshops and, since 2018, a highly successful programme of public science evenings. More recently in Autumn 2019 we joined forces with WMS to present a new "Science on the Hill" outreach series and SLS researchers (Profs Roper, Allaby, Dowson) contributed key events during the 2019 British Science Festival at Warwick (REF5a-4.3.4).

A new strategic initiative for SLS within this REF period has been the appointment of three Honorary Industrial Professors, aligned with our research themes: Dr Smith, Chief Scientific Officer and Corporate Director of Strategy for Gene Therapy, Cobra Biologics (aligned with Biomedical Science & Biotechnology and Synthetic Biology); Dr Puddephat, Senior Director for Agro Discovery & Sustainability from PepsiCo (aligned with Plant and Crop); and Prof Snape, Global Safety, Health and Environment Director, Astra Zeneca (aligned with Environmental Bioscience). These honorary positions give SLS strategic insight to the commercial sector and their remit stimulates exchanges between academia and business, especially on our industry days, PGR training events and at guest lectures to our UG and PGT students. WISB has a network of industrial partners on its advisory board including Ingenza, ATUM, Green Biologics and Microsoft.

By encouraging our researchers to seize opportunities to interact with stakeholders, we have developed a substantial portfolio of **Impact Case Studies** and are submitting 5 to REF2021. In parallel, we are supporting a much wider pipeline of projects with high potential for societal impact, including, for example, Prof Wellington's work with Severn Trent Water using metagenomics to map bacterial load in treatment plant effluent.

Research integrity is paramount in all we do. All academics complete the Epigeum course (REF5a-2.11) on research integrity, complemented for our students with workshops in research ethics, scientific data awareness and responsible innovation. SLS has a 100% record in submitting published manuscripts to the open access Warwick Research Archive Portal within 3 months and reviews all UKRI data management plans to ensure that there are clear and robust statements about secondary access and intellectual property protection (REF5a-2.10).

The future for the School of Life Sciences

Foster, Build, Train: three years into our strategy renewal implementation plan, we are achieving the three key objectives as outlined above. We are taking them forward by: opening the IBRB (£54M), further developing the School's activities at the Wellesbourne Innovation Campus, recruiting new staff (13 further R&T academic posts, 2 teaching fellows and 6 support staff over the next 6 years), continuing to invest in our pump-priming fund and industry vouchers, making use of the Warwick Impact Fund (REF5a-2.7) and seeking further engagement with the national industrial strategy, building partnerships with Innovate UK and networks supported by the UK's Industrial Strategy Challenge Fund. For example, to start redeveloping our unique resources at Wellesbourne Prof Napier is leading a task force to address "The Innovation Imperative for Horticulture", linking our Crop Centre's strengths to expertise across the university in engineering and rural economics. We will continue to work in partnership with the local community and seek charitable donations (e.g. Elizabeth Creak, £5M) to support focused, innovative scientific projects.

Summary: Our strategy for the future is to ensure that our community grows stronger whilst remaining cohesive, productive and successful, sharing its diverse expertise to tackle the world's sustainability challenges.

2. People

In developing the REF submission, the unit has operated within the University's agreed REF 2021 Code of Practice.

Fostering a culture of excellence

Crucial to the development of our research portfolio since the last REF has been the commitment of all staff to open, collegial and constructive discussion. Developing from the philosophy of Athena SWAN, we built a strong community at all staff levels and in which teaching and research are well integrated, everyone is valued, research excellence is fostered, interdisciplinarity is facilitated and impact is nourished. The success of this strategy is testified by our progression from Athena SWAN Bronze to Silver in 2018. The Athena SWAN team was led by Prof Bending and Dr Freeman (Director of Student Experience) with representation from across the School. Implementation of the Silver action plan is being led by Prof Boltze with the aim of achieving Gold status by 2022.

Representation is important for all branches of our community and we have established, for example, a Post-doc Society which runs a focussed wellbeing forum, mentoring scheme, and training workshops in e.g. grant writing skills. Our technical staff are encouraged to promote their careers as professionals through the University's Technician Commitment (REF5a-3.3). The Institution has established a transparent process for teaching staff to progress through to Professorial grades. SLS runs frequent community-building events for all staff and all postgraduate students such as annual away days, termly whole-School meetings, and a Christmas research showcase event.

Equality, diversity and inclusion (EDI) strategy

Since 2016, we have appointed 10 Assistant Professors to invest in early career talents with 50:50 gender balanced recruitment. We enable all colleagues to achieve their potential by proactively encouraging individuals to invest in personal growth and identifying and supporting staff with annual promotions and merit award processes. Our EDI committee informs our good practice,

supports staff with taking up institutional training and personal development, continues to ensure that our Athena SWAN Silver action plan goals are being achieved and is laying the foundation for a Gold application (REF5a-3.4). Two SLS-led initiatives, first developed within our EDI committee, and then taken up by colleagues across the University and more widely have been (i) our outreach programme of staff wellbeing and development workshops that we now run jointly with Warwick Medical School, and (ii) our analysis of student attainment that examines not only final degree outcome but also how students progress across years, with a focus on intersectionality. Dr Young, lead for this analysis, has recently been appointed to the Royal Society of Biology's Education and Science Policy Committee based on his expertise in this area.

When compiling our REF2021 submission we have reflected upon and ensured that we have considered EDI appropriately, in line with the Institution approach and REF guidelines. We also gained wide community input and annual institutional feedback on our submission.

Building a community: Academic staffing strategy

A key tenet of our strategy is that all staff are valued. For all categories of staff at all levels of seniority we regard inclusivity and diversity as important criteria so that we have a healthy balance of gender, nationality, senior/mid/early career researchers and support staff to ensure a supportive and collegiate community. For example, the whole School discusses and develops priority areas for staff appointments with direction from our research themes and Teaching and Research Strategy Committees and oversight from the Chair of the Faculty of SEM. By consensus, we have focussed on strengthening neurobiology, antimicrobial resistance, environmental biology and computational biology. Another element of our strategy was to evenly balance appointments of early career and senior appointments. We achieved this aim by advertising posts across levels, enabling us to select the most talented applicants at the level appropriate to them.

As part of our strategic drive to increase interdisciplinarity, SLS made four joint appointments with Mathematics (one professorial), a joint professorial post with Statistics, and two posts with Chemistry. An example is Prof Didelot (with Statistics) who replaced Prof Hollingsworth who is now Senior Group Leader at the Oxford Big Data Centre. Joint appointment academics are fully integrated into each department, hold office/lab space in both as well as proportionate teaching workloads in each department. All joint appointees have been successful in securing grant income (e.g. Prof Didelot's Health Protection Research Unit, £2M funded by National Institute for Health Research), and producing world class outputs (e.g. Dr Stansfeld (Chemistry) has published in Cell, Science, and Nature). This interdisciplinary mix is further strengthened by the work of our Industrial Professors, as described earlier.

Based on our proactive approach to renewing and growing our research community, we made key appointments that complement and extend the delivery of our interdisciplinary research agenda: appointments in statistical bioinformatics (Prof Didelot, joint with Statistics) and disease ecology and epidemiology (Dr Gorsich) filled vacancies left by career-led departures. Catalysed by the £10.5M BBSRC/EPSRC and Warwick funding of WISB (director Prof McCarthy) we strengthened the thematic area of Biotechnology and Synthetic Biology with 2 appointments, Prof Soyer and Prof Jaramillo. All new appointments have rapidly established themselves and achieved both funding and research successes. They have created many new collaborations within the School and brought disciplines together across the University. Highlights include Dr Hebenstreit who won a £2M EPSRC physics/life sciences interface award and Dr Asally and Prof Soyer who established successful spinoff companies (Cytecom and Humane Technologies).

Workload and staff development

SLS developed a workload model in 2012 that enables research, teaching and administration to be balanced and flexed annually according to the proportion of active grant commitments, fellowship time and significant leadership roles. R&T staff have an average of 35% time allocated to research and impact activities with a core, protected baseline of 20% to ensure that no academic is prevented from generating new ideas for research grants. The model is dynamic and based on the preceding three years of income, rather than an annual snapshot. As part of our Athena SWAN Silver action plan, time for impact and outreach activities is included in staff workloads. This model also accounts for time spent on administrative duties for the School or University, such as Director of Research or Director of Admissions, roles which are rotated periodically. These roles constitute significant career development opportunities (duly acknowledged by the University's recently redeveloped promotion criteria) and recruitment is by advertisement and selection among applicants. The workload model can also provide flexible arrangements for part-time staff and for staff that are returning from periods of leave. Our workload model is highly valued by staff since it enables them to plan their time effectively and feel valued for taking on roles that do not offer immediate personal benefit.

Supporting people and careers

Our staff support and development procedures are informed by our Silver Athena SWAN action plan. Recent successes include: introducing Deputy roles on senior leadership committees, opening our grant application hustings sessions to postdoctoral staff, and senior staff taking a proactive role in helping colleagues achieve promotion, for example by contributing to the University's Gender Task Force (REF5a-3.4). We have engaged with the University's work shadowing scheme for both academic and professional staff. All staff in the School of Life Sciences have annual Personal Development Reviews, a formal dialogue with a senior member of staff that helps to set goals and priorities for the coming year, reflect on past progress and identify where training would be valuable. For jointly appointed staff, PDRs are carried out with input from both heads of department to ensure that these colleagues are supported and developed across all the discipline areas that they work in. PDR reviewers for staff alternate over years in order for staff to benefit from a range of expertise and inputs covering research, teaching, impact and collegiality. Tangible benefits to our staff include 17 out of 17 members staff who have successfully applied for promotion as a result of PDR discussions since 2017, and many staff receiving short periods of workload relief to achieve personal goals. PDR discussions have also empowered staff to give feedback and make recommendations on how the School is managed, resulting in much improved scores for SLS in the institutional PULSE survey.

New staff support strategy

The teaching workload of new staff is protected, such that in their first and second year of appointment, academic staff typically only have 1/3 or 2/3 of the teaching workload of established staff, depending on level. For new staff on probation (Assistant Professor or Fellowship holders) a workload from around 1/4 of a full teaching workload is gradually increased over a period of five years, or until they complete probation.

Probationary staff have a review meeting with the HoS twice a year to discuss progress and training needs. They are also assigned a mentor who is normally a member of senior staff in their research theme, but they can choose who this is. Mentors provide support with research infrastructures and networking, grant applications and publications as well as help with developing good teaching practice, group management and outreach. New staff are given a generous start-up allowance as well as lab space with other relevant research groups so that they can share

equipment, ideas and expertise. We run a comprehensive induction programme to help them access all of the help that they will need to make rapid progress.

Our support mechanisms have allowed new staff to make rapid progress in winning grant funding as PI, typically within 18 months of appointment (e.g. MRC and Diabetes UK to Dr Harrison; NERC and ERC to Prof Chen; Wellcome Trust Seed awards to Dr Crow and Dr Nelson; Wellcome Trust Henry Dale fellowship to Dr Fullam; a Newton Fund award to Dr Sagona). Five recent appointments have completed probation early (Drs Asally, Harrison, Panfilio, Huckstepp and Dyson) and three have successfully extended existing independent Fellowships (Drs Ntoukakis, Corre and Fullam). Additionally, both Drs Asally and Sagona have successfully established spin-out companies (Cytecom and Lucidix Biolabs) while on probation, and several of those named have been able to achieve their successes whilst also supporting young families.

Sabbatical research leave

SLS offers sabbaticals for established members of staff, especially those who have carried significant administrative loads, and workload relief is available to all staff (including part-time staff) at all stages of their careers. Our policy sets achievable goals for the sabbatical period, for example delivering key impact activities, and examples of sabbaticals which have generated significant successes include Prof Napier (Industrial funding, a Leverhulme Trust Research Project award and 15 publications), Dr Wall (MRC application and a 4* Neuron paper), Prof Dowson (~£2M funding). Recently, Prof David Roper was awarded a prestigious \$200k Schaefer Research Scholar Award to spend 2020-21 carrying out infection research at Columbia University.

Development as researchers

SLS operates a comprehensive pre-submission peer review and support system for funding applications. All staff applying for UKRI and other substantive research grants present a short (5 minute) pitch at open access husting sessions, 2-3 months pre-deadline. Constructive feedback is given with plenty of time for improvements. The Director of Research chairs a review panel 2-3 weeks pre-deadline, with each applicant given a full review from internal referees and consultations on financial plans with time to polish their application.

SLS recognises the importance of being able to generate pilot data suitable for new grant applications and our Pump-Priming Fund (PPF) committee allocates up to £10K to promising ideas from all staff and PDRAs. PPF also offers industry vouchers to encourage links with non-academic organisations (which must contribute equally) and to promote our expertise in the regional bioeconomy. PPF has supported 120 projects (including 30 female and 23 ECR applicants) since Jan 2014, leading to 10-12 grant submissions every year and 15 external research awards from UKRI, Wellcome and Leverhulme Trusts. A total value of £8.7M since Jan 2014 is directly attributable to this seed funding. PPF also supports career progression, helped more senior staff establish new techniques and provides a timely resource for preliminary high risk-high reward experiments. For example, in the first years of her appointment, Dr Harrison won an MRC responsive mode grant after support from the PPF, and Prof Napier won a Leverhulme Trust award to start a project using DNA aptamers, a technique new to SLS.

Training: Development as professionals

We engage fully with the *UK Concordat to Support the Career Development of Researchers* and Warwick offers a wide range of training to staff through the Academic Development Centre (including professional skills and training to support mentoring such as student wellbeing and mental health) and from the Research and Impact Services group (R&IS; including grant writing skills) (REF5a-3.3, 1.7). Every year, 2 established members of staff are encouraged to take the

Warwick Leadership Programme (WLP), which enables academic staff from across all university departments to develop in or towards senior leadership roles. SLS runs its own programme of targeted training, for example a recent 'bootcamp' for grant applicants preparing their Je-S summary sections. We support staff to train for and participate in a wide variety of other activities such as industry days, public engagement events and outreach (described in Section 4). Similarly, we engage with *Technician Commitment* (REF5a-3.3, 4.3.2), running personal and professional development sessions and we have led in the institution by recruiting to higher grade technical job roles (e.g. senior experimental officer) and establishing a clear promotions pipeline.

Flexible working and care-for-careers

A strong feature of our Athena SWAN action plan is that we have implemented and promoted a policy of using SLS funds to extend the employment contracts of researchers who have a period of maternity, paternity or long-term ill health leave, to ensure that their research project and career is not disadvantaged. We provide HR and careers advice to researchers employed on fixed term contracts to ensure that they can consider, well in advance, what opportunities are available to them, including maximising redeployment opportunities to help retain talent. All staff may make arrangements for flexible working, for example four-day working weeks for some parents with school-aged children or flexible/staggered hours for those returning from illness and an increasing recognition that managed working from home can be highly productive. Responsibilities for supervision of students during such breaks will be taken on by the second supervisor. If time away has led to a gap in research project funding, our pump priming fund can help restart experimentation. These arrangements have improved retention of staff and overall job satisfaction, as evidenced by our PULSE survey.

Development of research-only staff

Research-only post-doctoral scientists benefit from the same opportunities and support structures available to R&T staff. We support many successful fellowship applications, thanks to our robust research governance structure. As a result, we have made SLS an attractive destination for excellent research fellows and provide bespoke support to applicants. Dr Alberti won a Leverhulme Trust Early Career Fellowship in 2018 with PPF support, and in 2020 Dr Carpenter and Dr Connolly were successful in securing UKRI Future Leaders Fellowships. Carpenter's fellowship followed his earlier appointment to a WISB Career Development Fellowship which was designed to prepare appointees for their independent research career. Our RSDO, Dr Kimura assists internal/external early fellowship applicants, arranges meetings and visits, provides strategic planning, consultations and reviews their proposals. For example, SLS supported Dr Kubes as a successful Marie Skłodowska-Curie Fellowship applicant from the Czech Republic in 2018. We actively encourage ECRs to engage with research supervision and to contribute to our teaching and outreach activities. Through careful mentoring and support, we have been successful in translating fellowships into permanent R&T posts for 5 researchers over the REF period (Drs Fullam, Christie-Oleza, Kistler, Sagona, Ntoukakis).

Supporting research student success

We have a vibrant community of 150 PGR students, the majority associated with our three highly successful interdisciplinary doctoral training programmes:

- BBSRC-funded Midlands Integrative Biosciences Training Partnership (MIBTP, led by SLS (Drs Ntoukakis and Penman) and recently renewed from 2019-2024 in partnership with Leicester, Birmingham, Aston and Harper Adams). The second largest BBSRC DTP, it hosts 68 students at UoW, 46 of which in SLS.

- Synthetic Biology CDT (in partnership with Bristol and Oxford, 11 UoW, 7 SLS)
- The Central England NERC Training Alliance (CENTA, in partnership with Birmingham, Leicester, Loughborough and the OU: 11 UoW, 7 SLS). CENTA was renewed in 2018 with a significant increase the Midlands PhD allocation by 50% for 5 years.
- The MRC DTP led by the Medical School (6 SLS).

Funding for additional PhD students also comes from BBSRC CASE studentships, an industrial CDT led by Waitrose (currently 3 SLS students), the Institutional Chancellor's International Scholarship scheme, Warwick Chancellor's Partnership Research Studentship which enables funding joint with a non-University partner, by industry (e.g. Astra Zeneca, GSK), charitable bodies, international scholarships (e.g. Commonwealth Scholarships and China Scholarship Scheme) and the EU, with a small number of self-funded students.

PGR governance is managed by the SLS PGR Management Committee (established in 2017), chaired by the Director and Associate Director of Postgraduate Research and attended by DTP directors, the Director of Education, PhD students and professional PGR administrative staff. SLS runs a programme of mandatory annual training sessions for all PGR supervisors to ensure that they are well-equipped to support the scientific and developmental needs of their research students. All students have two supervisors, which is of particular benefit for early career stage supervisors.

Our PhD students are integrated into well-supported, active research groups providing an excellent research experience, bespoke training and the chance to understand the expectations of a career in academic science. In addition to the structured training programmes associated with each DTP, the School has a programme of 'Masterclass' training workshops delivered by academics, R&IS or Warwick Ventures on specific research techniques, grant and paper writing, generation of impact and preparation of fellowship application etc. Recent graduates have moved to postdoctoral positions in other prestigious institutions including Cambridge, York, Cancer Research UK, Kew Gardens, Cornell, and the University of California. One of our PhD students, Dr Puxty, moved on to a post-doc position in the US before coming back very recently to Warwick as an Assistant Professor appointment after winning a NERC personal fellowship. Many PhD graduates have moved onto research careers in industry (e.g. Unilever, Johnson and Johnson, Syngenta) and careers in regulation and policy (e.g. Environment Agency, UKRI).

All PGR students gain from professional training opportunities offered and organised through Warwick Skills Forge and the chance to work with students across departments. For example, our UG and PGR students compete in the interdisciplinary iGEM International team competition every year. Many of our DTPs also give students the chance to experience a non-academic environment, for example the BBSRC Professional Internships for PhD Students (PIPS) within MIBTP. This has helped recent graduates to take up positions in industry, for example at Perfectus Biomed, and policy in positions at BBSRC and Defra. Career development for PGR students is also supported by the University's Institute of Advanced Study, which supports international Rutherford Fellowships, regional internships, KTPs and a comprehensive programme of business training run in collaboration with Warwick Innovations (REF5a-2.8), enabling PGR students to gain experience in entrepreneurship.

Visiting scientists and international exchanges

The School welcomes around 25 visiting researchers per year, from PGR to Professors, from a few days or up to a year, who come to share facilities and expertise. They enjoy all the benefits

accorded SLS staff and PGRs for the duration of their stay. Induction meetings are held with our Technical Lab Manager group and specialist technical and health and safety skills must be passed, ensuring that all work is carried out safely. We ensure that visitors are able to integrate well into our community via our research themes. Visits have helped to increase our interactions with stakeholders and have led to new grants and papers. For example, a collaboration between SLS and Glasgow on cell type responses to salinity in plants was driven by a PhD student from each institute and has led to a paper submitted to PNAS. All of these opportunities extend both our research scope and the global reach of our work.

In summary, our research community, from undergraduates and postdocs to technical staff, researchers and academics, thrives because of the practical and professional environment that we provide. We are constantly improving our support and will continue to promote excellence with collegiality - for all of our students, staff and stakeholders.

3. Income, infrastructure and facilities

Research funding: strategies for fostering research and building income

The success of our current strategy is testified by an overall research income of £81M across the REF period, with awards of £14.6M in 2020 alone, indicating a strong income pipeline. Income per academic FTE averaged £204K per annum. Significant research awards since in the REF period, by Research Theme, include:

Biomedical Sciences

- Nokes, Wellcome Trust - COVID-19 Intervention modelling for East Africa and improved respiratory virus intervention strategies, total awards £3.9M and **Impact Case Study**.
- Keeling, UKRI - COVID Modelling Consortium: quantitative epidemiological predictions in response to an evolving pandemic, total awards £771k
- Nokes, NIHR – Global health research group on application of genomics and modelling to control of viral pathogens in East Africa £1.9M
- Didelot, NIHR – Health Protection Research Unit in Genomics and Enabling Data £2M
- Ted Pridgeon Chair in Neurosciences awarded to Prof Dale, which enabled the development of the **Biosensors Impact Case Study**. Dale has won additional MRC awards totalling £1.6M
- Dale, MRC – Structure and biophysical basis of Connexin 26 channel mediated disease £1.1M
- Koentges, MRC – Connexin 26 mediated breathing control by the healthy and obese brain £1.3M
- Fullam, Wellcome Trust Sir Henry Dale Fellowship - Understanding the role of sugar transporters in Mycobacterium Tb; total awarded (including renewal) £1.5M – the initial fellowship award was renewed in 2019
- Dowson, MRC – Mechanism of understanding of cell wall biosynthesis £1.1M

Biotechnology and Synthetic Biology

- Soyer, BBSRC LOLA – Engineering synthetic microbiological communities for biomethane production £773K, and evolution of metabolic interactions using synthetic microbiological communities £751K.
- Hebenstreit, BBSRC – Genomic scaling of transcriptional noise £766K
- McCarthy, BBSRC – Warwick Interdisciplinary Synthetic Biology Centre £7.6M (total award circa £12M) and extension £2M
- Hebenstreit, UKRI – Transcription and nuclear phase transitions £923K

- Soyer, Gordon and Betty Moore Foundation, Symbiosis in aquatic systems investigator award - Understanding interplay between microbial interactions and spatial organisation £1.7M
- Jaramillo, ERC - General-Purpose Programmable Evolution Machine on a Chip £557K

Environmental Biosciences

- Scanlan, European Research Council - Cyanophage inhibition of oceanic CO₂ fixation. ERC-AdG £2.6M
- Chen, ERC – Ecophysiology of membrane lipid remodelling in marine bacteria £1.4M
- Wellington, BBSRC – Phosphor cycling in the soil microbe plant continuum of agri ecosystems £669K, and the farm environment as an overlooked reservoir of *Mycobacterium bovis* £780K
- Bending, BBSRC – Roots of decline? - Assembly and function of the rhizosphere microbiome in relation to yield decline £736K

Plant and Crop Science

- Allender and Barker, Defra - Genetic Resources Unit £1.9M. This collection has been used by over 40 seed companies and 200 research groups internationally and supports the Vegetable Genetic Improvement Network (VeGIN) £878K; included in our **Impact Case Study**.
- Allaby, NERC – Archaeogenomics of Sorghum domestication and adaption £633K. Has resulted in outputs in Science and Nature Plants.
- Holub, BBSRC – Developing genetics and genomics for sustainable use of resistance to white rot in oil seed mustard £1.2M
- Collier, AHDB – Sceptre plus; £1.2M. Disease, pest and weed problems in fresh produce and ornamental crops, and **Impact Case Study**.
- Elizabeth Creak Trust Chair in food security awarded to Prof Grant
- Donations totalling around £1.4M from the Elizabeth Creak Trust and the Brewster family for the Horticulture Technology Centre for Vegetable Improvement
- Grant, BBSRC - Xanthomonas plant diseases: mitigating existing, emerging and future threats to UK agriculture £1.2M
- Chandler, AHDB - Application and Management of Biopesticides for Efficacy and Reliability (AMBER) £1.2M

Strategies for generating research income

We have created a supportive environment around research income, where colleagues understand the importance of helping each other to create a strong pipeline of ideas. Our collegiality ensures ideas are strengthened to maximise grant success rates and outputs. Initiatives include School away days, mentoring junior staff, hustings and sandpits to generate and strengthen fundable concepts, internal peer review of proposals to replicate funder assessment processes, grant writing boot camps and workshops with funders to ensure that we learn about their expectations. We strongly encourage membership of UKRI grant assessment committees: currently 7 SLS academics sit on various UKRI research council Committees, and they in turn mentor staff in grant writing skills.

During the REF period we have provided significant match funding to help secure large external awards. Examples include £1.2M match funding towards the WISB programme award, 50% funding for our most recent ALERT-funded ion mobility mass spectrometer, and 1:1 matching of UKRI doctoral training partnership awards including the BBSRC MIBTP and NERC CENTA DTPs. Dale's MRC Discovery award was matched with a new lectureship and research budget.

Contributing to the University's Strategy of *Excellence with Purpose* (REF5a-2.1), our research strategy for 2017-2027, includes a 30% growth in academic numbers over 10 years. New posts will be in strategically important areas such as neuroscience, food security, environmental microbiology, infection biology, antibiotic resistance, synthetic and industrial biotechnology, with a focus on interdisciplinarity. This growth underpins our strategy to increase research income, creating depth and extend networks of excellence to lay the foundations for longer and larger grant applications. Our Research Strategy and Research Management committees include representatives from each theme, so that we are ready to seize opportunities when strategic calls arise.

Research income generation is linked to our human resources strategy and our staff development processes (annual review, promotion board, reward and recognition reviews). We discuss research income plans as part of cascading the School's strategy into individual work plans. Our recruitment strategy is underpinned by an expectation of healthy research income, and we support our recruits to help them realise success and generate this income.

We recognise the importance of multidisciplinary and have actively sought opportunities for joint academic appointments. We have 6 such appointments, involving Mathematics, Chemistry and Statistics. SLS researchers are instrumental in our strongly interdisciplinary research centres (WCC, WCIBB, WISB, WAMIC, WESIC, SBIDER) which bring together key academics from many departments across the University to focus on contemporary challenges. Organically grown collaborations can quickly take advantage of new funding calls as well as respond to calls for information that can shape funding opportunities. Examples of large research awards arising from such interactions include Hebenstreit's EPSRC funded work on transcriptional stochasticity with colleagues from Physics (Kantsler and Ball) and WISB having significant inputs from Chemistry (Challis) and Engineering (Bates). Prof Soyer's Bioelectricity Impact Accelerator Innovation Hub, BEE, is funded by BBSRC and is jointly steered by industry.

Our multidisciplinary Centres have also been particularly successful in building links with industry. WISB has generated an industrial network comprising 16 companies including GSK, BASF, Croda, Microsoft Research and Syngenta. WCC, the UK Vegetable GeneBank and its VeGIN networks draw all the major international crop breeding companies to their annual industrial stakeholder meetings. Innovate UK supports commercialisation of our research, e.g. Lillywhite (The Insectrial Revolution Project; £358K) and Asally (Rapid, portable, live bacterial cell detector ICURe; £107K). We continue to encourage multidisciplinary partnerships and to build on our successes.

Local support for income generators

In addition to our pump priming fund, our researchers have access to catalyst funds from the University, such as the Research Development Fund (RDF). For knowledge transfer to the bioeconomy, the Warwick Impact Fund (REF5a-2.7) and UKRI Impact Acceleration Accounts have helped to move several projects along the Technical Readiness Level scale including, for instance, our **Impact Case Studies** "Integrated Pest Management in horticultural crops", and "Genetic improvement of vegetable crops".

Our RSDO provides grant improvement workshops and engages with support structures across the university. R&IS prepare application budgets and SLS provides post-award financial administration. We deliberately recruited an RSDO who has been a postdoctoral researcher to ensure that we could provide informed and constructive advice. The RSDO also monitors

Researchfish completion, collates data for strategic initiatives, and supports early career researchers to succeed. R&IS staff attend our Research Strategy and Research Management meetings to ensure that they are part of our developing strategy.

Excellent facilities and technical expertise

The School's research strategy is enabled by our excellent research facilities and we provide researchers with core technical, IT and laboratory support facilities which include media preparation and waste management as well as supported specialist facilities such as our genomics centre, imaging suite, horticulture services, and the new Elizabeth Creak Horticulture Technology Centre. We have an excellent range of managed core communal equipment, including ultracentrifuges, containment and tissue culture facilities, cryostores and the WISB advanced technology platforms.

The University's strategy has led to the establishment of Research Technology Platforms (RTPs) which are open access, TRAC-costed facilities offering high-end instrumentation with support and training from specialist academics. Four RTPs are based in SLS: Proteomics, Dr Jones; Advanced Bioimaging, Dr Smith; small animal facility, Prof Frenguelli; Bioinformatics, Dr Ott (joint with Warwick Medical School). The School is implementing the Technician Commitment and investing in the continuing development of experienced technical support staff.

Our SLS Technical Assurance Manager works closely with the University Biosafety Officer to provide specialist advice and support for e.g. biohazard containment, including our Containment Level 3 labs, and radioisotope labs. Every laboratory has a technical manager who is involved with induction of new researchers, instrument maintenance and workplace good practice. This frees research staff to focus on their projects.

Support for data management, access and archiving

The library and IT services run comprehensive data storage and archiving facilities, including the WRAP open access portal, high-performance clusters, cyber security, and compliance with data protection legislation. Our SLS IT team add local support for our scientific equipment and curation of large datasets such as from 'omics and imaging.

Strategic support for research and impact

In line with the University's strategy for growth in STEM, the SLS strategy will see the School grow to 78 research active academic FTEs by 2025. Over the REF period the University also approved significant match funding investment in SLS researchers, including 5 four-year WISB Research Career Development Fellowships (£1M) and three WISB PhD studentships (£167K each). The University has also made significant investment in four doctoral training partnerships, namely MIBTP2020-2025, CENTA, SynBio CTP and the Waitrose CTP, adding a total of around 150 matched studentships.

Amongst the DTPs we have hosted 15 CASE studentships and ensured that all MIBTP students gain purposeful Professional Internships (PIPS), giving us visibility and traction with industry. We have dedicated Impact Managers who manage our impact case portfolio, collect vital documentary evidence of impact and oversee our IAA and FTMA awards. This superb infrastructure not only benefits SLS researchers, but also is highly attractive to an increasing number of new investigators and fellowship award holders.

Operational infrastructure supporting research and impact

The School operates across two campuses, Gibbet Hill and Wellesbourne. Both are well equipped with research labs and facilities (inc. stores, media prep, workshop, sterilisation and waste streaming), and are supported by our technical teams. Our policy is to share equipment and work as a community, which helps us to maximise research intensity, promote equity and ensure best use of our footprint.

Specialist research facilities include:

- Containment level 2 and 3 microbiology labs. A new modular £1.5M CL3 laboratory suite will be installed at Gibbet Hill in the Summer of 2021
- Primary tissue culture facilities
- The WISB technology hub incorporating £3.2 million equipment including flow cytometry, advanced microscopy and robotics
- A genomics hub providing qPCR and next generation sequencing
- Field, glasshouse, quarantine and polytunnel facilities. This includes irrigation, farm machinery and pesticide handling facilities supported by professional horticultural staff. We also support commercial crop trials (e.g. Corteva).
- The Innovate UK CHAP-funded demonstration £0.5M ETFE greenhouse. The first natural-light demonstration facility in the UK
- The Phytobiology Facility containing 13 glasshouse compartments, a 500 m² controlled environment hall and associated lab, containment and preparation areas
- The new £1.75M Horticultural Technology Centre, dedicated to gene editing improvement of vegetable crops.
- Three confocal microscopes (additional to the Advanced Bioimaging RTP)
- Proteomics RTP
- Advanced Bioimaging RTP
- Biomedical Services (small animal facility) RTP
- Scientific Computing RTP and the new Bioinformatics RTP with local bioinformatics servers supporting the latest high-throughput technologies, analysis of large datasets and digital simulations.

The Gibbet Hill Campus Development Group involves SLS, WMS, the Estates Office and a recently appointed planning professional and is chaired by the Faculty Chair. As part of the University's STEM grand challenge (REF5a-4.2), it is actively developing plans for the Gibbet Hill Campus to ensure that its built environment continues to support the ambitious growth plans of both schools, and matches modern quality expectations of both students and incoming research staff to match conditions in IBRB. The £54M IBRB will accommodate around 300 staff and PhD students, a 400-seat lecture theatre and space for formal and informal meetings and events.

Our Wellesbourne Campus offers an enviable range of facilities for plant and crop research including fully supported field, glass and controlled environment growing spaces. Supporting these are an insect rearing unit as well as excellent primary, secondary and plant pathology labs. The University is developing Wellesbourne as an innovation campus through the Wellesbourne Development and Investment group, with WCC as a focus for stakeholders from the commercial agriculture community. We have a strategic plan for which we are seeking funding that will see a fusion of horticultural science, advanced manufacturing (Warwick Manufacturing Group) and entrepreneurship (Warwick Business School) to support growing competitiveness in UK horticulture.

Wellesbourne also hosts the UK Vegetable Gene Bank with its unique collection of vegetable crop genetic diversity. Funded by Defra, it is an invaluable resource for vegetable improvement

worldwide, recognised in two Impact Case Studies. Wellesbourne also collects and holds long-term data sets on weather and aerial fly trap data, mineral-depleted fields with long term nutrient data, a quarantine field for pathology and a negative pressure glasshouse for pathogen and pest containment.

Our support infrastructure delivers a complete service for researchers and studentship holders across both campuses. We also arrange training opportunities with all the central university teams. For example, Warwick Ventures Ltd (Warwick Innovations) holds surgeries every week and has supported 6 start-ups and spin-outs since 2014, and we have joined Ximbio, the global, non-profit life scientific research reagents partnership to ensure that we capitalise on the reagents we develop.

Summary: By providing excellent facilities, a fully supportive infrastructure and championing technical expertise, our research ideas flourish, generate income and generate a legacy for society.

4. Collaboration and contribution to the research base, economy and society

Strategic partnerships with BBSRC and policy development

The University of Warwick is one of only 12 BBSRC strategic partners, based on SLS's profile as a leader in research areas of Food Security and Industrial Biotechnology. SLS contributes expertise to four BBSRC responsive mode committees with over 10 pool and core members over the REF period (7 current). For example, Dr Gifford sat on the last three ALERT panels, and is currently on Committee B and the sLoLa panel. Dr Jones is on the ALERT2020 panel, Profs Chen and Roper on Committee B and D, respectively. Prof Green chaired Committee A before moving on to Council and she also served on the BBSRC animal welfare network committee. For NERC, Prof Wellington has served on the Environment and Human Health panel, and Prof Scanlan on the Biomolecular Analysis Facility Committee. Prof Dowson sat on the MRC immunity and Infection Board and Prof Wellington the Antimicrobial Resistance Strategy Steering Group. Prof Bending has served on 10 NERC and BBSRC panels, including as chair for the NERC Emerging risks of chemicals in the environment panel in 2018. Prof Grant sits on the UKRI Bacterial Diseases of Plants co-ordination committee.

Fostering leadership in international partnerships and research networks

The UK Vegetable GeneBank at the Wellesbourne Campus is part of an international research initiative in food security to curate and distribute rare and valuable horticultural germplasm. It has sent seeds to over 40 plant breeding companies and over 200 academic researchers across the globe. SBIDER has large number of partnerships with international governments and NGOs. Prof Nokes is the principal investigator at KEMRI, the Wellcome Trust Medical Research Institute in Kenya, where he heads the virus epidemiology and control research group, which is at the frontline of national COVID-19 control. SBIDER also has extensive links with international government (US Department of Agriculture, National Institutes of Health, China CDC, Philippines Bureau of Animal Industry, Kenya Ministry of Agriculture and Kenya Medical Research Institute, DRC Ministry of Health) and non-governmental organisations (World Health Organisation, Food and Agriculture Organisation of the United Nations, World Organisation for Animal Health, EuFMD, International Livestock Research Institute). The School is an active member of the Warwick Brazil Partnership SPRINT (FAPESP-Warwick Joint Fund) and a major initiative was the establishment of a Transatlantic Synthetic Biology Research Triangle involving Warwick, São Paulo and Boston University, USA. Academics enjoy partnerships with CUSP (New York); Singapore (NTU and

NUS); the FioCruz Institutes in Brazil (Recife and Curitiba); the University of São Paulo, Brazil; Ethiopia, Kenya Agricultural Research Institute, Africa; Monash University, Melbourne; Boston University and Harvard, Boston, USA, and SLS established a joint Virtual Laboratory with Northwest Agriculture and Forestry University (NWFU), China in plant and crop sciences in 2019. In 2019/20 Dr Schaefer was part of the largest Arctic research expeditions ever planned with the German research ship RV Polarstern. Prof Allaby collaborates with The Smithsonian (USA) on the archaeobotanical evidence of crop domestication pathways, leading to recent publications in Science and Nature Plants.

Fostering national partnerships

In our Biomedical Sciences theme, Prof Keeling, Drs Tildesley and Dyson currently advise SAGE on COVID-19, sit on the Department for Health's Scientific Pandemic Influenza advisory group and the Joint Committee on Vaccination and Immunisation, as well as the BBSRC Animal Disease Working Group; Dr Khan has served on the panel of experts for the National Institute for Health and Care Excellence. In the Crop and Plant Science theme, Prof Collier chairs the EU Insecticide Resistance Advisory Committee; Prof Walsh is President of the International Working Group for Legume and Vegetable Viruses. In the Environmental Biosciences theme, Prof Bending sat on the UK Government's Expert Committee on Pesticides until 2019. Prof Napier and Dr Barker serve on Innovate UK review panels and Dr Barker has served on the Innovate UK Steering Committee.

Building leadership across the academic community

In addition to leading collegial activities for national funding agencies, academic staff contribute expertise to specialist community activities. Dr Smith sits on the World-wide Protein Data Bank Scientific Advisory Board and the EMBL-EBI Molecular and Cellular Cluster Scientific Advisory Board. Dr Jones serves on the advisory board for IntACT and Complex Data Portal at The European Bioinformatics Institute, Dr Corre serves on the Royal Society's Newton International Exchanges Committee, Dr Purdy has served on Marie Skłodowska-Curie Fellowship selection panels, Prof McCarthy has represented the University on the iCREA Fellowships Committee in Catalonia and the Synthetic Biology Institute SAB, Tartu, Estonia, and Prof Collier is a member of the Insecticide Resistance Action Group (IRAG). Prof Cameron is on the British Crystallographic Association Committee, Drs Smith, Fullam and Prof Gutierrez-Marcos have served on committees of the Biochemical Society, Profs Thomas and Collier on Royal Horticultural Society Committees, Prof Gutierrez-Marcos on the Genetics Society, Dr Courtenay on a Marie Curie ITN Advisory Board and Profs Napier, Dowson, Easton and Collier on the strategy Board of the charitable Medical and Life Sciences Research Fund. Dr Khan sits on the NICE panel as an invited expert and also acts as an Executive Director of Silence Therapeutics plc, a company exploiting RNAi technologies as therapies. Prof Grant serves on the UK Plant Sciences Federation Executive Committee and was on the GARNet Steering Committee.

Research-led collaborations building partnerships with commerce

The School has contracts with 64 diverse funding organisations in addition to UKRI; 33 from outside the UK. Partners include charities, other national funding agencies including the industry-led levy board AHDB, and businesses in addition to the links with commercial and research agencies attracted to our RTPs. Over the REF period 42 UKRI awards have involved industrial partnerships, including LINK awards, IPAs, strategic initiatives and Research Club initiative awards.

SLS developed and leads (Drs Ntoukakis & Penman) the highly successful doctoral training partnership MIBTP. MIBTP continues to grow with a greater number of industry-linked studentships annually and, at its successful renewal in 2019 was awarded 245 studentships over

5 years. In addition, the University of Aston and Harper Adams University became partners alongside Birmingham and Leicester. Similarly, Prof Scanlan developed CENTA which is a consortium of Universities and research institutes funded by NERC. SynBio CDT was developed by Prof Soyer in WISB. The Waitrose-led CDT led by Prof Collier trains students in key skills in areas of horticulture relevant to their business model. All these energetic training networks foment regional collaboration. Recent research-led collaborations with the regional bioeconomy include 15 CASE studentships and 4 Warwick Collaborative Postgraduate Studentships.

All our research themes have wide collaborative networks. Highlights by Theme include:

Biomedical Science: Dr Nokes has a KEMRI/Wellcome Trust NIHR Global Health Trust award (£1.9M); Prof Dowson won GCRF funding for developing the next generation of beta-lactamase inhibitors with the University of Cape Town (South Africa), the development and validation of assays and reagents to exploit the final steps of peptidoglycan synthesis with AstraZeneca (USA) in a LINK award, and runs the UK-China hub for antibiotic discoveries (£0.5M); Dr Courtenay runs field trials of synthetic sandfly sex pheromone to reduce human visceral leishmaniasis transmission (£0.75M) with Brazilian partners WT STA; Dr Rock won £0.4M from the Gates Foundation for human African trypanosomiasis modelling for an international team to inform national control programmes. Prof Hollingsworth arranged the Non-Transmissible Diseases modelling project for the Gates Foundation.

Biotechnology and Synthetic Biology: Prof Jaramillo collaborates across Europe on EVOPROG, a programmable evolution machine on a chip (£0.56M) and on PROMYS: Programming synthetic networks for bio-production of value chemicals (£0.54M) which has partners in Spain, Denmark, Netherlands, Germany and Switzerland; Prof Roper won support from Basilea Pharmaceuticals (Switzerland) for work on the biochemistry of peptidoglycan precursors, and a BBSRC LINK award for inhibitor discovery in peptidoglycan biosynthesis (Merck, USA).

Environmental Sciences: Prof Wellington won £0.4M for developing fast assays for pathogen identification and characterisation with the University of Lyon (France); Prof Bending works with Velcourt Farms on “Roots of decline?” which studies rhizosphere microbiome in relation to yield decline (£0.74M); Prof Collier runs the SCEPTRE Plus project for AHDB (£1.2M) which coordinates applied research on high priority disease, pest and weed problems in fresh UK produce.

Crop and Plant Sciences: Dr Jackson has funding with partners in Brazil (Agronomy Institute/São Paulo Agribusiness Technology Agency (APTA), the USA (University of Wisconsin) with a BBSRC-NSF award, and with Prof Hong at the Research Centre for Plant RNA Signaling, Hangzhou Normal University in China, with whom he has set up a joint laboratory at Hangzhou for exploiting viral vectors in crop improvement. Dr Barker is PI on the VeGIN project (£878K); Prof Napier works with Corteva Bioscience on next-generation auxins (Indianapolis, USA, £0.9M). In 2019 Warwick became an active member of the UK’s Crop Health and Protection (CHAP) consortium which was established under Innovate UK’s Agritech catalyst initiative. CHAP has constructed an Innovate UK-funded novel ETFE greenhouse (£0.5M) at Wellesbourne.

Building local partnerships

We have strong partnerships with the Coventry University, University Hospital Coventry and Warwickshire, and AHDB, the UK levy board, which helps maximise the reach of our work at local and national levels and benefit people in our communities. Every year we host multiple work experience placement students from local schools, with a particular focus on widening

participation (WP) students from disadvantaged backgrounds. Prof Moffat has worked nationally with the Sutton Trust Summer school program, engaging 50 students in biomedical and health related sciences in two years. He has also worked with the regional Engineering Development Trust, running the only summer life sciences program in their portfolio, hosting 30-50 students per annum. We also work locally with the University's own Warwick Scholars scheme to provide activities and support for these pupils in higher education applications.

Fostering equipment and facility collaborations to promote knowledge exchange

The Warwick RTP model (REF5a-4.3) is specifically designed to be accessible to researchers from other institutions and from industry, and the University has set up Warwick Scientific Services (WSS) to permit service-driven use of both RTP equipment and other advanced facilities within SLS. WSS has pre-prepared contracts and pricing schedules to make it quick and easy for external users to arrange access. Industrial partners are also encouraged to exploit recognised collaborative research models such as LINK awards (as for Roper, noted above), Industrial Partnership Awards (Gutierrez-Marcos and others), CASE studentships and our industry vouchers. For academic collaborators we operate a light-touch visitor process for use of our instrumentation, with appropriate help and guidance from our facility managers.

Dr Smith leads Warwick's contribution to the Midlands Regional Cryo-EM Facility, the result of a successful £3.7M bid to MRC by Leicester, Warwick, Birmingham and Nottingham, and our structural biologists are part of the user community at specialised equipment facilities such as offered by Instruct-ERIC, the Membrane Protein Laboratory and DIAMOND at Harwell. Some of our BBSRC Flexible Talent Mobility Awards, Innovation Fellowships and KTPs share expertise with companies and return knowledge to our academic community. For example, SLS has had 2 KTPs with Elsoms Seeds Ltd, and FTMA awards with Domainex, Xerion (drug discovery) and LifeArc (high-throughput drug candidate screens).

Generating funding for collaborative facilities

SLS proactively draws expertise from non-UoA5 departments within Warwick. Highlights include leadership in the development of the multidisciplinary WISB (Prof McCarthy), and the associated SynBio DTP which is joint with Oxford and Bristol. Dr Smith led a successful ALERT14 bid for cryo-electron microscopy at Warwick. Dr Jones led the successful ALERT19 bid for new mass spectrometry instrumentation for proteomics. SLS academics have led or co-led large successful bids, e.g. to BBSRC NIBB (Soyer), Gates Foundation (Keeling, Hollingsworth), European Commission Horizon 2020 (Wellington), Newton Fund (Sagona, P Schafer), Royal Society GCRF (Grant), EPSRC Building Collaboration at the Physics of Life Interface (Hebenstreit), NIHR HPRU (Didelot).

Research leadership at the national level – training communities

We have a huge range of collaborations that engage with key research users and diverse audiences. Our research also translates into local and national impact over a broad sphere of activities. Notable examples include: Prof Leppard, Prof Easton and Prof Dimmock published the essential and popular university textbook "Introduction to Modern Virology". Prof Green was awarded an OBE (2017) for her services to the health and welfare of farmed livestock. Prof Collier was awarded the Veitch Medal by the Royal Horticultural Society for outstanding contributions to the advancement of the science and practice of horticulture. We have academics on 35 committees or advisory boards for national funding agencies, and 28 academics on journal editorial boards, leading and influencing their disciplines.

Building an infrastructure for impact

The School's strategy is to expand the role of the RSDO with the remit to encourage more KTPs, facilitate impact networks and arrange focussed stakeholder events. We actively encourage staff to apply for UKRI IAA and FTMA awards for both immediate and longer-term case studies. IAAs provide seed funding to develop collaborations with users of research and the BEE innovation hub (Prof Soyer) represents one such successful partnership. The FTMA supports the development of promising leaders of the interface between academic and industry, with our partnerships with Domainex, Xerion and LifeArc enabling new research to make impact.

Our Research Strategy Committee with the R&IS Impact team (REF5a-2.6) manages our impact portfolio as a database (currently comprising 45 case studies), encouraging and developing future case studies. Our internal peer review system requires a well-considered impact assessment and delivery plan at a very early stage of each grant application and we deliver regular impact-building training workshops. Costs for impact activities are monitored post-award to ensure that these are well delivered.

Seeding new businesses

The School actively supports staff and fellows to exploit intellectual property. Our thriving spin-out companies are:

- Sarissa Biomedical Ltd (Prof Dale)
- Cytecom Ltd (Dr Asally)
- Antimicrobial Screening Facility (NEQAS accredited; Prof Dowson)
- Lucidix Biolabs (Dr Sagona)
- Humane Technologies Ltd (Prof Soyer)
- Virion Biotherapeutics (Prof Easton)

Wider contributions to the regional bioeconomy

- Sarissa has created 20 jobs in the Warwick Science Park
- Cytecom Ltd (Dr Munehiro Asally) employs one director
- MicroPathology Ltd: Prof Fink is an SLS honorary professor and SLS has trained the majority of the company's current staff. The company, a major COVID analysis centre, also hosts many undergraduates for their placement year in industry, DTP student miniprojects and PIPS.
- Prof Dowson's Antimicrobial Screening Facility employs one scientist at Warwick
- Humane Technologies Ltd employs one scientist at Warwick

Engagement with other non-academic communities

Since early 2020, members of SBIDER have been advising SAGE on the COVID pandemic: Prof Keeling and Dr Tildesley have frequently appeared on national and international media throughout the pandemic. Prof Easton has also featured on international newscasts about coronaviruses.

Outreach and community training

SLS has a dedicated outreach team led by Prof Moffat. Our well-established public engagement programme has informed and entertained at high-profile festivals such as Cheltenham Science Festival, the Big Bang, the British Science Festival and, locally, the Kenilworth Agricultural show. Workload is allocated for outreach activities and the team works with children from Foundation Stage (Reception year) up to Sixth Form students and the general public. We also provide CPD sessions for teachers via Warwick CTE. All members of the department are encouraged to participate in outreach activities: undergraduates and administrative staff helping with science evenings, open days and competitions; academics, technicians, post-docs and postgrads

presenting at Pint of Science, Café Scientifique and other community events. A notable success has been our public science evenings – held approximately every 6 weeks. Initiated by Prof Dale and now supported by our RSDO Dr Kimura and Prof Moffat, we regularly have 100 visitors from the public for 2 hour sessions to learn directly from the School about exciting topical research. In 2018 we delivered outreach to over 2,000 students from approximately 100 schools across the country and this is repeated annually. Testament to our leadership in outreach we have been chosen to host the British Biology Olympiad each year from 2013, culminating in the honour of hosting the International Biology Olympiad in 2018. Led by Prof Moffat, Drs Williams and Gifford challenged, enthused and evaluated 264 student competitors from 68 countries in both theory and practical tasks.

Summary: SLS provides an environment where collaboration, entrepreneurship, and communication are valued and enabled. We encourage researchers to develop their vision with the wider research base, to realise the impact of their work in the bioeconomy and to entertain and inform the wider society with exciting news of their discoveries.