Institution: Newcastle University

Unit of Assessment: UoA7 Earth Systems and Environmental Science

a. Overview:

This submission draws on research from specific groups within the Schools of **Civil Engineering and Geosciences**, **Marine Science and Technology**, and **Biology,** all within the Faculty of Science, Agriculture and Engineering. It spans the areas of **Geochemistry**, **Biodiversity** and **Biotechnology** with 24.6 FTE staff comprising 13 Professors, five Readers, 10 Lecturers/Senior Lecturers, three externally funded Research Fellows and RAs and includes 4 ECRs.

In the REF period we have held £20M in research awards; £8.2M from RCUK, £3M from the EU, £4.2M from industry and £4.6M from NGOs and government departments/agencies in the UK and abroad, resulting in research spend of over £12.5M, leading to 442 outputs listed in WoK. We have particular strength in fundamental and applied science relevant to **unconventional hydrocarbon resources**, **climate change**, **management of biodiversity** and **control of biofouling**. Collectively we address Newcastle University's societal challenge theme of 'sustainability' as central stakeholders in the Newcastle Institute for Research on Sustainability (NIReS; http://www.ncl.ac.uk/sustainability/). Established in 2010 as a vehicle for interdisciplinary research across the University, NIReS has a central role in providing infrastructure and coordination permitting us to realise our ambitions beyond the bounds of school structures and subject silos.

b. Research strategy:

1. Achievements in relation to RAE2008

In **RAE2008** our submission covered three groups, **Geoscience**, **Marine Ecology** and **Marine Biotechnology**. Recruitment of new staff, inclusion of staff previously submitted under other UoAs and strategic changes in research direction are reflected in our achievements elaborated below.

Energy supply, **climate change**, and **sustainability** were identified as the broad strategic drivers of our research in RAE2008 and provide the foundation for our research achievements in the REF2014 period. Selected achievements are highlighted here under our three discipline groups (* ***indicates paper not returned as a REF output in REF2***):

i. **Geochemistry**: Abbott, Gray, Head, Hubert (ECR), Jones, Larter FRS, Manning, Maerz, Talbot, Upstill-Goddard, van der Land (ECR), Wagner.

i.a. *Unconventional geoenergy and the deep biosphere (strategic driver - energy supply)*

While it is essential to decarbonize our energy economy, Energy Information Administration (www.eia.gov/) projections indicate that fossil fuels will still meet 85% of global energy demand as far ahead as 2035. Cognisant of this reality, managing the transition to low carbon energy supply demands that we develop more effective recovery of energy from fossil sources, with reduced greenhouse gas emissions. This continues to inform our geochemistry/microbiology research.

Electricity production from methane leads to around 30% and 45% less CO_2 per kWh of energy generated than oil or coal respectively. We have therefore proposed that in situ conversion of heavy and/or residual oil to methane could be a route to lower emissions energy recovery from oil reservoirs. This requires an understanding of the distribution of microorganisms in petroleum reservoirs, as well as information on their kinetics and growth yields which were until very recently unknown, or inferred from geochemical gradients in reservoir oil columns. We have now shown that microbial populations are focussed in the oil water transition zone, providing vital information on where to target treatments to stimulate microbial activity (*Bennett et al., 2013, Org. Geochem., 56, 94-105: Head REF output*). We have also identified key organisms for methanogenic crude oil biodegradation and established quantitative relationships between microbial conversion of oil to methane and microbiological parameters (*Gray et al., 2011, Environ. Microbiol., 13, 2957-2975: Jones REF output*). This is a key step in the development of low emission microbial recovery of energy from stranded residual oil, which can be more than 70% of oil in place in a reservoir.

i.b. *Carbon capture and storage (strategic drivers - energy supply, climate change, sustainability)*

With continued use of fossil fuels it is incumbent upon us to recapture the fossil carbon released. Our research on carbon storage in natural carbon reservoirs and geoengineering approaches to carbon mitigation complements our fossil fuel-related research. We have shown that afforestation significantly affects the antioxidant capacity of soil and consequently carbon recalcitrance (*Mason et al., 2009, J. Anal. Appl. Pyrolysis, 85, 417-425; Schlichting, et al., 2013, Soil Biol. Biochem., 58, 16-26: Abbott REF outputs*). This has important implications for the design of geoengineering strategies for more efficient carbon capture in soils and peats. Explicitly geoengineering-focussed research has demonstrated that urban soils have the capacity to capture CO_2 as stable carbonates (*Washbourne et al., 2012, Sci. Total Environ., 431, 166-175: Manning REF output*). Moreover,

Manning has co-authored an influential perspective article in *Nature* discussing the potential of soil organic carbon as a repository for carbon, thus playing a key role in the carbon management agenda for the soil science community (**Schmidt et al., 2011, Nature, 478, 49-56*).

i.c *Biogeochemistry and climate change (strategic driver - climate change)*
Our research encompasses elements of both present and past climate change. This has explicit links to our research in fossil fuels and carbon sequestration in relation to petroleum source-rock formation and the effects of carbon burial and preservation on global climate. Our palaeoclimate researchers have determined that 116M years ago a global temperature drop of up to 5^{o}C was as significant to marine life as periods of global warming. The cooling event triggered a major shift in the global carbon cycle by burying approximately 812,000 GT of carbon. This resulted in a drop in the levels of atmospheric CO_2, reducing the greenhouse effect and lowering global temperature (*McAnena et al., 2013, Nat. Geosci., 6, 558-561: Wagner REF output*).

Understanding the factors that control air-sea exchange of climatically active trace gases is a core strand in our biogeochemistry research. This has demonstrated the importance of surfactants in modulating air-sea gas transfer velocity (*Salter et al., 2011, J. Geophys. Res., 116(C11), C11016: Upstill-Goddard REF output*), the effect of sea ice on Arctic Ocean CH_4 budgets (*Kitidis et al., 2011. Mar. Chem., 121, 80-86: Upstill-Goddard REF output*), and that European estuarine contributions to global N_2O are around two orders of magnitude less than thought (*Barnes et al., 2011, J. Geophys. Res., 116(G1), G01006: Upstill-Goddard REF output*).

ii. Biodiversity: Bythell, Edwards, McGowan, Mill (ECR), Polunin, Stead, Tosh (ECR), Whittingham, Wolff.

ii.a. *Global biodiversity loss (strategic drivers - climate change, sustainability)*
Our research contributes to all stages of the conservation process. Cataloguing the biodiversity on Earth is on-going and we continue to contribute to this international knowledge base. We have discovered novel marine ecosystems and species (**Rogers et al., 2012, PLoS. Biol., 10, e1001234: Polunin*) and we have carried out leading work analysing large datasets in order to describe the changes in abundance (*via* proxy measures) for a wide range of organisms. Specifically, we have shown the global decline of 25,000 species of vertebrates (*Hoffman et al., 2010, Science, 330, 1503-1509: McGowan REF output*) and 845 reef-building coral species (*Carpenter et al., 2008, Science, 321, 560-563: Edwards REF output*).

The group has also explored the drivers of population change and, for example, we have demonstrated the role of immunity in susceptibility to coral reef bleaching, a major threat to coral reef communities globally (*Palmer et al., 2012, Philos. Trans. R. Soc. B-Biol. Sci., 279, 3879-3887; Bythell REF output*). Not all proposed drivers of change were previously supported by evidence. We have now shown that wind turbines do not have an effect of displacement of farmland bird species, a group that has declined rapidly in Europe over the last three decades (*Devereux et al., 2008, J. Appl. Ecol., 45, 1689-1694: Whittingham REF output*).

We have used our scientific evidence base to explore ways to minimize declines in biodiversity by prioritizing efforts where they can yield greater results or additional co-benefits. For example, by (i) identifying key species within marine ecosystems that maintain function and so should be prioritized for conservation action (*Graham et al., 2011, Ecol. Lett., 14, 341-348: Polunin REF output*); (ii) demonstrating that management for biodiversity across a broad range of European case studies also benefits other ecosystem services (*Kenward et al., 2011, Proc. Natl. Acad. Sci. U. S. A., 108, 5308-5312: Whittingham REF output*).

iii. Biotechnology: Bentley, Burgess, Caldwell, Clare, Goodfellow, Stach.

iii.a. *Biofouling (strategic drivers - climate change and sustainability)*
Biofouling of ships' hulls alone is estimated to increase fuel consumption by maritime shipping by up to 40% contributing to an estimated cost of $60 billion annually. Coupled to increased greenhouse gas emissions (c. 384 million tonnes CO_2) and translocation of invasive species, the economic and environmental consequences of failing to control fouling are clear. Our fundamental and applied research on biofouling is aimed at new solutions for its control. A focus on barnacles, as major fouling organisms, has informed technologies that interfere with the ability of their cyprid larvae to colonise surfaces. Among our recent achievements, we have advanced understanding of the mechanism of cyprid reversible adhesion (*Aldred et al., 2011, ACS Appl. Mater. Interfaces, 3, 2085-2091: Clare REF output*;**Aldred et al., 2013, PLoS One, 8, e68085: Clare*) and demonstrated that coatings that interfere with this process are promising nontoxic alternatives for fouling control (**Aldred et al., 2010, Biofouling, 26, 673-683: Clare*; *Tasso et al., 2012, Adv. Funct. Mater., 22, 39-*

47: Clare REF output). Moreover, our research on silicone coatings containing carbon nanotubes (**Beigbeder et al., 2008, Biofouling, 24, 291-302: Clare*) was instrumental to the successful launch of a new class of coating.

iii.b. *Natural products (strategic driver - sustainability*)
The frequency of rediscovery of known natural products, notably antibiotics, from actinomycetes that are common in well-studied habitats is high. It is therefore vital to isolate and screen previously undiscovered members of this economically important group of bacteria. We were solely responsible for devising the selective isolation, dereplication and taxonomic strategies that led to the discovery of two novel dermacocci that synthesise dermacozines. Dermacozines are active against leukaemia cell lines (*Abdel-Mageed et al., 2010, Org. Biomol. Chem., 8, 2352-2362: Goodfellow REF output*). We have shown that taxonomically-novel actinomycetes from neglected habitats are likely to have undiscovered biochemical pathways and demonstrated that a taxonomic roadmap can be used to identify organisms with novel genes and metabolic capabilities (*Bringmann et al., 2009, Chem. Commun., 44, 6810-6812: Goodfellow REF output*). By applying a stringency measure we have shown that some essential proteins make better targets for inhibitors than others (*Goh et al., 2009, PLoS One, 4, e6061: Stach REF output*). We have also shown that the traditional medicine Berberine is an inhibitor of FtsZ, a bacterial cell division protein and target for new antibacterials (*Boberek et al., 2010, PLoS One, 5, e13745: Stach REF output*).

2. Overarching vision and strategy for the future

i. Vision

Expertise spanning three Schools and several disciplinary strengths is brought together through NiRES and provides us with the breadth and depth required to tackle major challenges facing humankind and the environment. Solutions to these challenges are unlikely to come from within traditional scientific boundaries and their credibility will depend on their social and societal impact and acceptance. Our core disciplines provide us with the skills and tools needed to understand the fundamental biology, chemistry and physical processes that drive our planet and, through NIReS, we access expertise in social science and engage with policymakers and stakeholders. This, together with close interaction with engineers in the schools contributing to this UoA7 submission, allows us to realise our ambition of translating our science into sustainable management of the environment.

Strategic new appointments and inclusion of staff previously submitted under other UoAs have led to changes in our skills base and development of our current and future research direction. On this basis we have identified three major challenges that represent an evolution from our RAE2008 submission and form the basis for our future research strategy.

Challenge 1. Managing the transition from fossil fuels to a low carbon economy
Challenge 2. Management of biodiversity for conservation and sustainable exploitation
Challenge 3. Biotechnology for sustainable applications in the environment and human health

The contribution of our research groups to these challenges can be encapsulated in relation to the more specific research they undertake. The **geochemistry** group seeks to understand Earth's life-support systems. Central to this are links between the geosphere, Earth surface and (micro)biological processes. Understanding the drivers of modern and past climate change links intimately with this goal and we apply (bio)geochemical understanding to solve problems relevant to future energy supply and climate change mitigation. In the face of the sixth extinction phase in biodiversity and increasing human populations the **biodiversity** group seeks to identify drivers of biodiversity change and evidence-based solutions to human-wildlife conflicts across a spectrum of ecosystems (e.g. invasion of alien species, disease spread, sustainable fisheries). Research in the **biotechnology** group aims to find solutions to the sustainable exploitation of the ocean and terrestrial environments in the areas of food, trade, natural products and energy.

ii. Strategy

The strategy informing our future research, and plans to realise the strategy, are articulated in relation to the three challenges we identify above. International, national and stakeholder collaboration are central to our research strategy, and we will bolster our interdisciplinary research and build for the future with key new appointments.

Challenge 1. Managing the transition from fossil fuels to a low carbon economy
Strategy: *Enhanced collaboration between key academic researchers, stakeholders in business*

and government and exploitation of new technology.
Plans: This challenge is directly tackled by our geochemistry research and is relevant to our biofouling research which will contribute to lower fuel consumption and emissions of CO_2 and other climatically active gasses, for marine shipping

We will continue to work closely with industry and have agreements in place with a number of leading global conglomerates in the oil and resources industries for ongoing collaboration. As we have done in the past, we will continue to hold engagement activities both in Newcastle and on-site with partner companies to facilitate this. Our focus on unconventional energy (*Wagner, Head, Jones* and *Gray*) will exploit the opportunities offered by the RCUK catalyst funding schemes and we have already made moves in this direction in collaboration with Professor Aplin who recently moved to Durham University from Newcastle. Unconventional sources of geoenergy are likely to be increasingly important in the global energy mix and our microbiologists will cement their links with internationally leading academic groups in this field (Biology and Earth Science groups in the Universities of Calgary and Alberta; *Head, Hubert, Gray* and *Jones*) by stronger interaction with Genome Canada's Hydrocarbon Metagemomics programme and continued RCUK, EU and industry collaboration on the biogeochemistry of petroleum systems (e.g. OILSPORE, PETROBIOME and KILL*SPILL projects). We will further strengthen this area with a Chair appointment in Petroleum Systems and a lecturer in a related discipline. In addition we recently invested in new staff with expertise in source rock geochemistry (*Maerz*) and carbonate systems (van der Land, ECR). This provides a direct link with research in carbon capture and storage where we will extend our research through, for example, collaboration with the UK Biochar Research Centre (*Manning* and *Gray*). Our international reach in this area will be facilitated by our involvement in the science advisory committee of Carbon Management Canada (*Head*). The innate linkage between organic carbon in the geosphere and the global carbon cycle provides the perfect platform that links our fundamental research on palaeoclimate and organic geochemistry with our applied research conducted in collaboration with the energy and environmental sector (*Wagner* and *Maerz*). We are also part of a NERC Oil and Gas CDT bid led by Heriot-Watt University offering opportunities for our specialised skills to be integrated with petroleum geology and engineering.

Our excellence in biofouling research (*Clare*) has relied on close engagement with international government stakeholders (e.g. ONR) and business (e.g. International Paint Ltd, AkzoNobel) and our bioenergy research (*Caldwell*) will be enhanced in the future through engagement with organizations such as Scottish Bioenergy and Seaweed Health Foundation. New end users are being engaged through EC programmes (e.g. SEAFRONT a 4-year programme beginning in 2014; *Clare*), participation in large international research programmes (e.g. ONR marine antifouling programmes; *Clare*), KTNs (e.g. new Algal SPARK Award; *Caldwell*) and other TSB funding schemes (e.g. new antifouling award; *Clare* and opportunities such as Catapult). NIReS will promote and extend stakeholder engagement and we will continue a programme of open days for industry, as organised by *marine*Newcastle (http://www.ncl.ac.uk/marinenewcastle/) in 2012 with EPSRC Bridging-the-Gaps funding. Our biofouling, biologically-focussed research in geoenergy and biofuels research all also contain elements relevant to **Challenge 3** below.

Challenge 2. Management of biodiversity for conservation and sustainable exploitation
Strategy: *Integrate and inform fundamental science with social and economic considerations to achieve sustainable conservation outcomes*

Plans: With increasing human populations there is a pressing need to understand and manage the issues arising from the interactions between humans and wildlife (e.g. invasion of alien species, and disease spread). Our vehicle for increasing our understanding of the interactions between humans and wildlife is the recently established Centre for Wildlife Management and Conservation (established in June 2013; *Whittingham, McGowan, Mill,* and *Stead*). The Centre is a formal collaboration between the wildlife management unit at DEFRA's Animal Health and Veterinary Laboratories Agency (AHVLA; formerly FERA) and staff in the Schools of Biology and Marine Science and Technology. The work from the Centre will capture underlying biological principles and apply them to practical management and the policy and regulatory environment dictating the management requirements. We will establish ourselves as a major player in conservation science by recruiting new staff and through the Centre for Wildlife Management and other vehicles to promote and support our research. We have begun by recruiting *McGowan*, an expert in international conservation, who has already established a new charity 'Conservation Balance' closely aligned to Newcastle University (*McGowan* and *Whittingham* are Trustees).

Key factors in realising this strategy are engagement with stakeholders and cross-disciplinary collaboration. NIReS has an important role to play in this and has kick-started interdisciplinary collaborations. NIReS has been particularly important for the nexus of natural and social scientists. MAPISCo (Method for the Assessment of Priorities for International Species Conservation; http://www.ncl.ac.uk/marine/research/project/4508) led by *Whittingham, McGowan* and *Stead* is a direct result of this approach. This DEFRA-funded programme will identify global conservation priorities for UK government taking account of social and economic dimensions. Further interdisciplinary proposals e.g. for the DEFRA Sustainable Intensification Programme focussed on sustainable agriculture are also being developed through NIReS.

NIReS managed our use of EPSRC Bridging The Gaps funding (2010) to form a Newcastle University local interest group on marine renewables, which has recently led to the formation of the North Sea Research Partnership (NSRP) in 2013 with other UK based partners (Universities of Durham, East Anglia, Hull, Cranfield, and the National Renewable Energy Centre). Initially, the partnership will focus on pursuing research into the environmental impacts and engineering efficiency related to renewable energy installations. The NSRP has received NERC knowledge exchange, and seed corn funding to facilitate its formation, and support pilot studies in areas as diverse as the bio-acoustic effects of wind farm installations on marine mammals, to the direct effects on bird mortality through collisions with turbine blades. In the context of the latter example, engineers are being engaged to develop sensors for real-time monitoring of bird strikes.

Challenge 3. Biotechnology for sustainable applications in the environment and human health
Strategy: *Extend international collaboration, engagement with key stakeholders, develop the activity of spin-out companies and exploit recent technological advances.*
Plans: Our research on novel bioactive compound discovery has relied on close collaboration with the biotechnology business (e.g. Croda Enterprises Ltd., Unilever and Novozymes AS). We will continue research and development of new products and services via our spinout company (Geneius; *Stach*) and in collaboration with industry through Demuris (*Goodfellow*). With the emergence of synthetic biology there are huge opportunities at the interface between our environmentally-focussed research and state-of-the-art molecular biology. We intend to make full use of these opportunities through school research groups (e.g. Applied Marine Science), NIReS, and Centres, including the Centre for Bacterial Cell Biology (http://www.ncl.ac.uk/cbcb/: *Burgess*), Centre for Synthetic Biology and Bioexploitation (http://www.ncl.ac.uk/csbb/: *Stach,Goodfellow* and *Head*) and Sir Joseph Swan Centre for Energy Research (http://www.ncl.ac.uk/energy/:*Caldwell*).

c. People

To deliver our research strategy we recruit staff in emerging areas and ensure that current staff are empowered both to develop new research themes and take a leading role in our current research.

i. Staffing strategy and staff development:

We balance recruitment of well-established senior researchers with maintenance of a stream of excellent scientists at earlier career stages, which we consider an important investment for future success. Our commitment to ECR is illustrated by our recruitment and staff development strategy.

i.a. Recruitment, development and promotion of new talent: Proactive identification and recruitment of research leaders for the future has been a major success of our staffing strategy. Our strategy of targeting high calibre researchers and supporting them in their applications for prestigious externally-funded Fellowships has allowed us to identify researchers with exceptional promise and potential for future research leadership. This provides first-rate opportunities for our ECRs and allows us to plan our future academic staff profile by mentoring our best Fellows for senior faculty positions. This has been a major success and in the REF period we have recruited 11 researchers with competitively awarded fellowships, including highly prestigious fellowships such as RS and NERC (*Hubert*, *Tosh*); BBSRC (*Whittingham*); EPSRC (*Hubert*); ERC (*Talbot*) and a number of Marie Curie Fellows. As a consequence, over the REF period six have been appointed to full academic positions (*Talbot*, *Hubert*, *Whittingham*, *Maerz*, *Zerkle*, *Poulton*) including two ultimately promoted to personal chairs (*Whittingham* and *Poulton*). Two have subsequently taken up senior faculty positions at Leeds (*Poulton*) and St. Andrews (*Zerkle*). This explicitly demonstrates the success of our recruitment and staff development programme in producing independent research leaders of the highest calibre, whose skills are in high demand.

To bolster our talent-development strategy we have pioneered internal fellowship awards to provide support to allow excellent researchers to develop new collaborations and exploit networking opportunities. These provide modest funds that can be used flexibly to take new ideas to preliminary proof of concept in support of funding applications, and bridging funds between

research contracts. These are awarded through an annual competition and have been so successful that they have now been adopted at Faculty level. EPSRC has recently recognized our Faculty Fellowship scheme by making fellows eligible for PI status on EPSRC proposals. We are working with other RCs to extend this and enhance opportunities for our most talented ECRs.

i.b. International recruitment: Since 2008 we have appointed five members of academic staff from overseas and we have had an explicit drive to attract international Research Fellows through a range of highly competitive routes (e.g. NERC, EPSRC, BBSRC, Royal Society, Marie Curie). 40% of our overseas appointments to faculty positions have resulted directly from initial recruitment as externally-funded research fellows.

i.c. Staff development and support: The core of our staff development and support systems is our annual performance and development review (PDR) process. The PDR revolves around a Personal Research Plan (PRP), which documents an individual's future research ambitions. In PDR staff reflect on their achievements, and set targets for the future in relation to their PRP. Advice is given on publication strategy, research collaboration and funding opportunities as well as on dissemination and networking activities and balancing of research, teaching and administrative workloads which are planned via a comprehensive workload model which ensures that ECRs have an increased allocation for research and controlled teaching and administrative duties.

We are fully committed to the Concordat agreement to support the career development of researchers and in September 2010 the University secured the European Commission HR Excellence in Research award for policies and practices supporting Concordat principles in 2009. Following a recent review, the University has retained the award for a further two years until 2014.

Newcastle University's HR team provides guidance on all aspects of the University's commitment to equality and diversity; in employment of staff, providing teaching and learning to students and being engaged with local communities (see http://www.ncl.ac.uk/diversity/about/). Newcastle University achieved the Athena Swan Bronze Award in 2009, aiming for silver by 2015.

ii Research students

We provide an outstanding environment for research training by embedding students within experienced research teams. We strive to achieve a high ratio of postdoctoral researchers to PhD students to provide students with a high level of hands-on project-specific training and prioritise this above maximizing the number of graduate students. This also provides our students with excellent access to our networks of international collaborators. Our in-lab training is augmented by strong institutional provision of a postgraduate skills development programme and progression system implemented through a dedicated online system (e-portfolio). Training includes bespoke courses on transferrable skills and obligatory M.Sc. modules that, through a system of credits, contribute to research student progression. An annual Postgraduate Conference is held in all the Schools submitting to UoA7 and students are provided a budget to attend two national and one international conference during their study. We operate to maximise the quality of our research students via a competitive process of appointment and proactive recruitment from our Masters courses which we use to identify students with excellent research potential. We have a portfolio of studentships involving industrial partners, either through fully funded industry studentships, jointly funded industry projects using industrial contributions to augment doctoral training account (DTA) funds, and CASE studentships. We currently operate a cohort-based approach to our graduate student provision and this has placed us in an ideal position to capitalize on the NERC DTP model. We are a partner in the £5M 'IAPETUS' NERC DTP which will recruit over 60 PhD students per year, and our specialist skills in petroleum geochemistry are incorporated into a NERC Oil and Gas CDT bid led by Heriot-Watt University. These will be important instruments for enhancing the experience of our graduate research students and providing them opportunities to develop cross disciplinary research and links with non-academic partners, vital for their career development.

d. Income, infrastructure and facilities

i. Income summary: UoA7 research enjoys a healthy, mixed economy, funding base. In the REF period active research awards exceeded £20M: RCUK (41%), EU (15%), industrial (21%), NGO and government departments/agencies (23%).

ii. Investment in specialist equipment and infrastructure: The group has enjoyed significant investment in infrastructure in the REF period with £4.1M spent on laboratory refurbishment and other estate, £5.9M on specialised equipment, and £1M on a new research vessel. Investment in the shore station serving the vessel has totalled c. £1M with contributions from the European Coastal Fisheries Fund, the Coastal Fisheries Community Fund, Port of Blyth, Northumberland County Council and the University. The Dove Marine Laboratory has benefited from £350K investment for refurbishment including new facilities for cetacean research. To ensure the

sustainability of our research infrastructure we have planned reinvestment of c. 5% of research income and Schools and Institutes produce on-going plans for major equipment purchase and develop strategic partnerships and alliances with other research organisations to maximise potential for external funding to support investment in equipment.

iii. Key facilities: We have excellent research facilities, with recently refurbished laboratories in all three schools contributing to UoA7. This has been supported by external (e.g. Wolfson Foundation), as well as central University funds. We benefit from centrally managed facilities supported by an analytical facilities manager and a cohort of excellent technical staff. In addition to a large number (>40) of experimental and sample preparation laboratories used by research groups, we have extensive molecular biology facilities (including an ion-torrent PGM) and a suite of centrally managed equipment, laboratories for gas and liquid chromatography, organic, inorganic and stable isotope mass spectrometry analysis. Significant items of equipment include a Thermo Finnigan Delta V Plus, compound-specific GC-isotope ratio mass spectrometry and a recently purchased Acquity UPLC-MS-MS with a Waters Xevo TQS MS and Agilent 7700 ICP-MS. Our strong links with the University of Calgary provide us with access to state of the art ultra-high resolution FT-ICR-MS facilities that are invaluable in our geoenergy research. These facilities equip us with the core capacity to conduct high quality geochemical studies and integrate these with modern quantitative and qualitative microbial community and process analysis. We also have a unique thermal analysis/gas sorption facility (Wolfson Northern Carbon Reduction Research Laboratory) and thermogravimetric analysis facilities which are invaluable in our carbon capture and storage research. The EPSRC XPS surface analysis facility is located in Newcastle, and we are partners in the EPSRC XR-CT facility located at Durham University which adds a new dimension to our analysis of soils, sediments and other complex geomaterials relevant to e.g. carbon capture.

Electron and optical microscopy facilities are available through central Electron Microscopy Research Services (http://www.ncl.ac.uk/emrs/) and Bioimaging Unit (http://www.ncl.ac.uk/bioimaging/), offering scanning and transmission EM, confocal microscopy (including multiphoton) and a Nikon N-SIM/N-STORM super resolution microscopy system.

In addition to laboratory facilities our research vessel, the RV Princess Royal (http://www.ncl.ac.uk/marine/facilities/princessroyal/) and shore station provide us with offshore sampling capabilities and includes a 6 x 5 l Rosette water sampler with integral CTD unit fast repetition-rate fluorometers and C-DOM sensors, a range of plankton nets and water sampling facilities as well as grabs and corers for sediment sampling. This is essential for our marine biogeochemistry and biofouling research as well as the fisheries and cetacean research of our biodiversity group. The Dove Marine Lab provides aquarium facilities and facilities for biofilm research and biofouling control test facilities. Our biofouling research benefits greatly from links with marine engineers in the School of Marine Science and Technology providing access to fully instrumented hydrodynamic lab facilities and a cavitation tunnel which can be used for example to test the effects of biofouling on ship and propeller efficiency. In addition Bythell's joint appointment with the University of Fiji offers unique access to field sites for our coral reef researchers.

iv. Computing facilities: Increasingly our work (especially in relation to genomic, metagenomic and high throughput microbial community analysis) requires access to high performance computing facilities. In addition to access to cloud-based computing facilities we have access to six Blade servers, two GPU arrays and use of a 300 node Condor cluster for distributed computing applications. We have a bioinformatics support group (http://bsu.ncl.ac.uk/support/) for 'large data' projects, such as next-generation sequence, proteomics and microarray analysis with customised pipeline creation as required.

v. Support for research development

Central support is provided for the development of larger funding bids within the UoA and in strategic partnership with other institutions. We have excellent support teams that collate and distribute research funding intelligence, provide strategic advice on approaching different research funders and organize high level internal peer review to maximize the quality of submissions. A component of our successful strategy of attracting high calibre researchers internationally has included investing in and supporting new staff in areas that strategically develop our research portfolio (e.g. a new cryogenic (4K) ^{57}Fe Mössbauer spectrometer is currently out for tender).

e. Collaboration and contribution to the discipline or research base:

The 114 research grants active in the REF period involved 157 collaborating organizations. These included 37 UK universities and research institutes, 58 European universities and research institutes, 18 other international universities and research institutes and 34 industrial partners.

We are very active internationally with 97% of our submitted staff publishing papers with international collaborators. Over 60% have active collaboration with industrial or other research users and over 70% have given plenary/keynote presentations at international conferences. Many of our staff are representatives on science advisory committees for international programmes or international peer review panels (>60%). Almost half hold positions on industrial or government advisory panels. In the REF period, submitted staff have held prestigious visiting professorships at Caltech, USA (*Head*), University of Manitoba, Canada (*Hubert*), Rhodes University, South Africa (*Bentley*), Hainan Normal University, China (*McGowan*), Research Institute of Petroleum Exploration & Development, PR China (*Larter*) and the University of the South Pacific, Fiji (*Bythell*).

In addition to the normal expectation that our staff are active on national Peer Review Colleges (>50%) and in the peer review system as editorial board members (c. 70%), several of our staff hold senior editorial positions on leading journals. *Whittingham* is a Senior Editor of the *Journal of Applied Ecology*; *Head* is a Senior Editor on *The ISME Journal*; *Burgess* is Editor-in-Chief of *Marine Biotechnology*; *Bentley* is Managing Editor of *Invertebrate Reproduction and Development*; *Clare* is Editor-in-Chief for the *Journal of Marine Science and Engineering*; *Polunin* is Editor-in-Chief of *Environmental Conservation*.

The contribution of our researchers to their respective disciplines is recognized by election as Fellows of learned societies and academies including the Royal Society (*Larter*, FRS); The Royal Society of Canada (*Larter*, FRSC); The Linnaean Society (*Bentley*, FLS); The Society of Biology (*Bentley* and *Head*, FSB); The Institute of Marine Engineering, Science & Technology (*Clare*, FIMarEST) and The European Academy of Microbiology (*Head*). In addition, *Goodfellow* was the Chairman of the Board of Trustees of Bergey's Manual Trust between 2008 and 2011 and is a member of the American Academy of Microbiology.

We also hold senior positions in scientific organizations, *Manning* is President Designate of the Geological Society (full President from 2014), involving a major role advising government policy on e.g. minerals and shale gas. He was also the only academic representative on the CBI's Future Minerals Scenario workshop, examining future mineral resources in the context of the World Economic Forum's 2030 scenario planning exercise. *Stead* was elected President of European Aquaculture Society (2008-2010) and was a member of their Board of Directors (2000-2012). *Caldwell* is a member of the Council of the Challenger Society and *Clare* is a National Oceanography Centre Association Board member and serves on the IMarEST's Biofouling Management Expert Group. We are well-represented on advisory boards of national and international governments, and many international organizations. *Stead* is a Marine Scotland Scientific Advisory Board Member and was a ministerial and DEFRA Scientific Fisheries Adviser, North Eastern Sea Fisheries Committee (2005-2011). *Stead* has also been appointed as a high level strategic adviser to the European Commission, Leibniz Institute, Germany, Indonesian Government and Swedish Research Council on research and development in marine science and technology. Working with Newcastle City Council, *Stead* was instrumental in securing the headquarters of the Marine Management Organisation (MMO) in Newcastle upon Tyne, cementing Newcastle's position as a leading centre for marine science and technology. *Polunin* is a member of the DEFRA Marine Fisheries Science Advisory Group and *Caldwell* has been a member of Foreign and Commonwealth Missions to New Zealand and China.

Until 2010 *Bythell* sat on the UNESCO Intergovernmental Oceanographic Commission *ad hoc* Committee on Coral Bleaching, the GEF/World Bank Targeted Working Group on Coral Bleaching and the US National Oceanic and Atmospheric Administration, Coral Disease Histopathology Working Group; *Larter* is the Scientific Advisor to the Chief Geologist of Petrochina; *Clare* served on the Science Advisory Board of A*STAR (Agency for Science, Technology and Research) in relation to Singapore's marine fouling programme (2012).

Edwards and *McGowan* have sat on or chaired a range of International Union for Conservation of Nature (IUCN) Commissions and Panels and *Edwards* was invited by the World Bank and Global Change Institute to lead the team developing part of the World Bank/GEF "Capturing Coral Reef & Related Ecosystem Services" (CCRES) project in the Philippines and Indonesia (2012). *Wagner* is Chair of the International Iwokrama Science Committee of the International Centre for Rainforest Conservation and Development, Guyana.

Our staff have also received prestigious awards and prizes in the current REF period, including an MBE awarded to *Goodfellow* for his services to education; Canadian Society for Petroleum Geology Medal of Merit (*Larter*); the Pieter Schenck Award from the European Association of Organic Geochemists (*Talbot*); Mineralogical Society Distinguished Lecturer 2009-2010 (*Manning*).