January 2015

Research Excellence Framework 2014:

Overview report by Main Panel B and Sub-panels 7 to 15

REF2014

Main Panel B

Executive summary

1. The purpose of this report is to provide key data on submissions, feedback on the process of assessment, and an overview of the research submitted to Main Panel B's sub-panels in REF2014.

2. Main Panel B saw an increase in high quality research submitted compared to the previous Research Assessment Exercise (RAE2008). The submissions demonstrated the strength of research in the UK in physical, mathematical and computer sciences, and in engineering. Overall 26 per cent of the research was assessed to be world-leading (4*), 57 per cent internationally excellent (3*), 15 per cent internationally recognised (2*) and 2 per cent nationally recognised (1*), where these averages are weighted according to the number of Category A full-time equivalent (FTE) staff included in each submission.

3. Not only has the quality of the research submitted increased since RAE2008, the FTE number of Category A staff submitted and Category A and C headcount have increased by 9.1 per cent and 7.5 per cent respectively. There were increases in the number of staff submitted to each of the physical sciences sub-panels, to the Computer Science and Informatics sub-panel and to the engineering sub-panels overall. Within engineering there was a redistribution with more staff submitted to the General Engineering sub-panel (an increase of 68 per cent Category A FTEs) and less to the individual engineering disciplines. The number of staff submitted to the Mathematical Sciences sub-panel was approximately constant.

4. Sub-panels noted an increase in the amount of interdisciplinary research and in research from collaborative working across higher education institutions (HEIs) both in the UK and with international partners.

5. 20 per cent of outputs were judged to be world-leading and a further 61 per cent internationally excellent. In spite of the increase in the number of staff submitted to Main Panel B, there was a slight reduction (2.7 per cent) in the number of submitted outputs due to the greater use, compared with RAE2008, of the arrangements for the submission of early career researchers and other staff with individual staff circumstances, which allowed staff to be submitted with less than four outputs each.

6. In this first assessment of impact, Main Panel B found evidence of many outstanding impacts, judging 38 per cent of the submitted impact to be outstanding and a further 46 per cent very considerable. While some research was planned to produce the impact reported in a case study, a significant proportion of Impact case studies was found not to have been predicted or planned when the research was undertaken. The panel considers it important to acknowledge that research can lead to unanticipated impacts.

7. The average FTE-weighted environment sub-profile for the main panel as a whole was 38 per cent world-leading, 37 per cent internationally excellent and a further 13 per cent internationally recognised. There was clear evidence of investment in people. Approximately 20 per cent of staff submitted to Main Panel B were early career researchers. Training and career development support appears to be widely embedded in institutions with many reporting initiatives to support equality and diversity. The number of doctoral degrees awarded rose 23.5 per cent between the first and last years of the assessment period. Annual external research income (excluding in-kind income from the UK Research Councils) has risen in real terms by 9.1 per cent between the first and last years

of the assessment period (using HM Treasury deflators to account for the effects of inflation). However, funding from the Research Councils, the largest funder in physical sciences and engineering, has fallen by over 9 per cent in real terms, making for a difficult funding environment over the assessment period. Despite this, there is evidence of diversification of funding sources, with significant growth in European Union (EU) and industrial funding contributing to the overall growth, and evidence of focussed investment in infrastructure.

Overview of submissions and results

8. Main Panel B received submissions as summarised in Table 1 below. The total number of submissions to the main panel decreased compared with RAE2008 (403 compared with 485), while the Category A staff FTE and Category A and C headcount have increased by 9.1 per cent and 7.5 per cent respectively. The panel welcomes this increased staff submission volume across the physical, computer and mathematical sciences and engineering disciplines.

9. There were increases in the volume of staff submitted to each of the physical sciences sub-panels, to the Computer Science and Informatics sub-panel and to the engineering sub-panels overall. Within engineering there was a redistribution with more staff submitted to the General Engineering sub-panel (an increase of 68 per cent Category A FTEs) and less to the individual engineering disciplines. The number of staff submitted to the Mathematical Sciences sub-panel was approximately constant. In a small number of cases, the increase in submission volume was attributable in part to opening of new departments or the re-opening of departments.

10. In contrast to the increased submitted staff volume, the number of outputs submitted to REF2014 was 2.7 per cent lower than submitted to RAE2008. This reduction in average number of submitted outputs is attributed to an increase in the proportion of staff returned with less than four outputs where their individual circumstances significantly constrained their ability to produce four outputs or to work productively throughout the assessment period. The panel welcomes this increased use of individual circumstances as a mechanism to allow institutions to submit all eligible staff who have produced excellent research.

Table 1: Submissions to REF2014 and comparison with submissions to RAE2008

UOA		Number of submissions	Category A staff FTE	% change in Category A staff FTE	Category A and C staff headcount	Number of outputs	Outputs per Category A and C staff headcount	Impact case studies
MPB	2014	403	13,347	+9.1%	13,930	49,317	3.54	1,667
	2008	485	12,234		12,998	50,669	3.90	-
7	2014	45	1,381	+17.1%	1,489	5,250	3.53	175
	2008	42	1,179		1,280	5,091	3.98	-
8	2014	37	1,229	+6.8%	1,267	4,698	3.71	152

UOA		Number of submissions	Category A staff FTE	% change in Category A staff FTE	Category A and C staff headcount	Number of outputs	Outputs per Category A and C staff headcount	Impact case studies
	2008	33	1,151		1,233	4,930	4.00	-
9	2014	41	1,705	+1.1%	1,774	6,446	3.63	203
	2008	42	1,686		1,793	7,156	3.99	-
10	2014	53	1,931	+0.4%	2,005	6,995	3.49	236
	2008	115	1,923		2,029	7,707	3.80	-
11	2014	89	2,045	+11.2%	2,159	7,665	3.55	280
	2008	81	1,839		1,910	7,491	3.92	-
12	2014	25	1,153	-9.5%	1,193	4,154	3.48	138
	2008	43	1,274		1,348	5,222	3.87	-
13	2014	37	1,071	-11.9%	1,113	4,028	3.62	141
	2008	54	1,216		1,292	4,965	3.84	-
14	2014	14	391	-23.8%	418	1,384	3.31	51
	2008	23	513		544	2,066	3.80	-
15	2014	62	2,447	+68.3%	2,555	8,697	3.40	291
	2008	52	1,454		1,569	6,041	3.85	-

11. The overall results of the assessment are shown in Table 2 below. This shows the average overall quality profile for each Unit of Assessment (UOA), and for the main panel as a whole. The average is calculated by weighting each submission in the UOA (or main panel) by the number of Category A staff FTE in each submission. This method is also used to calculate the FTE-weighted average sub-profiles in Tables 5, 7 and 8 below.

Table 2: Overall quality profiles (Category A FTE-weighted averages)

UOA	Name	Average percentage of research activity judged to meet the standard for:				
		4*	**3***	**2***	**1***	**U**
	Main Panel B	26	57	15	2	0
7	Earth Systems and Environmental Science	24	59	15	2	0
8	Chemistry	28	63	9	0	0
9	Physics	28	60	11	1	0
10	Mathematical Sciences	29	55	15	1	0
11	Computer Science and Informatics	26	44	24	5	1
12	Aeronautical, Mechanical, Chemical and Manufacturing Engineering	25	57	17	1	0
13	Electrical and Electronic Engineering, Metallurgy and Materials	25	62	11	2	0
14	Civil and Construction Engineering	24	56	16	3	1
15	General Engineering	26	56	16	2	0

12. Overall, for both the main panel as a whole and for individual UOAs within the main panel, there has been an increase in quality compared with RAE2008. The panel believes that there are a number of factors contributing to this increase, including a significant improvement in the quality of submitted research outputs, the introduction of impact in the assessment, which was found to be impressive across all panels, and a more structured assessment of environment, which has meant that results are not directly comparable with the RAE. Further discussion of the output, impact and environment profiles is included in the sections on each below.

Panel working methods

13. In all aspects of the assessment process, Main Panel B and its sub-panels adhered to the published assessment criteria and working methods set out in the Assessment Framework and Guidance on Submissions (REF02.2011) and the Panel Criteria and Working Methods (REF01.2012). At each stage of the assessment process, sub-panels made recommendations to the main panel on the outcomes of assessment and all results were approved by the main panel as a whole.

Main panel working methods

14. In particular, the main panel had a key role in ensuring cross sub-panel consistency in assessment standards, employing a range of mechanisms to support this.

15. Main panel calibration exercises were undertaken for outputs and for impact case studies and templates. In all cases, the main panel calibration sample included items from all Main Panel B sub-panels. These items were then also included in subsequent sub-panel calibration exercises, which included additional larger sub-panel specific calibration samples. Detailed discussion at main panel allowed sub-panel chairs to explore in detail the application of assessment criteria and standards, drawing on the input of international members, particularly in relation to outputs, and main panel user members, particularly in relation to impact items. This experience, together with agreed main panel advice, then supported the sub-panel calibration exercises.

16. As this was the first time that an assessment of impact had been included, an impact case study calibration exercise was also carried out across the four main panels.

17. It should be noted that the assessments resulting from calibration exercises were disregarded following completion of the calibration exercises and these items subsequently allocated in the normal way to panellists for assessment.

18. Main Panel B had six international members who brought expertise which covered the range of Main Panel B disciplines. A number of them had expertise which spanned several sub-panels. International members contributed fully to the work of the main panel and took a particular role in ensuring the international comparability of assessment standards for outputs, as well as having an oversight of the management and governance of the overall assessment process. They participated in a number of sub-panel meetings dealing with the calibration and assessment of outputs and provided input to the handling of grade boundaries for outputs assessment.

19. The international members expressed their confidence in the assessment process. They were impressed by its robustness, credibility and comparability across disciplines and its effectiveness in dealing with disciplinary differences. They noted the effectiveness of the calibration process but felt that perhaps more time could have been spent on calibration. They noted that the exercise was well managed with effective governance of the process.

20. Main Panel B had three user members who brought expertise in a number of relevant industry and government areas. Main panel user members contributed fully to the work of the main panel and took a particular role in the assessment of impact. Each main panel user member participated in the meetings of several sub-panels when dealing with the assessment of impact, and they were therefore able to provide valuable input to the consistency of assessment across sub-panels. They also provided input to the handling of grade boundaries for impact assessment.

21. The main panel user members observed the assessment process to be robust and found that working across a range of sub-panels was effective. They considered that calibration exercises were very important and their effectiveness might be enhanced in future exercises by the use of larger calibration samples.

22. The main panel was supported by a secretariat consisting of three panel advisers. Each adviser was also responsible for guiding the work of a cluster of three of the nine sub-panels, and the sharing of the advisers across sub-panels proved very beneficial in helping to ensure consistency of assessment processes across the sub-panels.

23. The main panel chair also attended a number of sub-panel meetings to observe their work and to check for consistency of approach and assessment standards.

24. The main panel reviewed the assessment outcomes emerging from the sub-panels' work. This was undertaken on an ongoing basis as work was completed by sub-panels to allow consistency of assessment to be monitored. All sub-panels made recommendations to the main panel on sub-profiles and overall profile for each HEI in their submissions, with the main panel collectively approving these results.

25. The main panel members believe that these working methods led to consistent standards being applied across all sub-panels in the main panel.

Sub-panel working methods

26. As noted in the discussion of main panel working methods above, sub-panels undertook calibration exercises for outputs, impact case studies and templates, with these exercises following on from the main panel calibration exercises and including the items from the specific sub-panel which had been considered in the main panel exercise. Output assessors were fully involved in output calibration and impact assessors were fully involved in impact calibration. In addition, some main panel international members contributed to output calibration and main panel user members contributed to impact calibration, in both cases, working across a number of sub-panels. In addition sub-panels undertook an exercise to discuss the approach to environment assessment ahead of undertaking this task. As noted previously, the assessments resulting from all calibration exercises were disregarded following completion of the calibration exercises and these items allocated in the normal way to panellists for assessment.

27. As set out in the criteria and working methods document, sub-panel chairs, consulting with deputy chairs and other panellists as appropriate, allocated work to sub-panel members and assessors with appropriate expertise, taking account of any conflicts of interest. Research groups, where given in the submission, helped in this allocation. Output assessors and impact assessors worked in the same way as panel members in relation to the assessment of outputs and impact respectively, including workload and contribution to the sub-panels' recommendations. All sub-panel memberships also included full panel members identified as user members because they came from industrial, government or similar environments rather than the academic community. While in some cases, depending on expertise, these members had either zero or reduced output workloads, they contributed fully to the assessment of impact and environment, and to the work of the panel overall. Their participation and commitment was appreciated by sub-panels.

28. Only a very small number of outputs for which double-weighting was requested were submitted to Main Panel B sub-panels. These were considered first by the panellists to whom they had been allocated for assessment, who judged the merit of the case made for double-weighting based on the criteria. Recommendations were made to, and considered by the relevant sub-panel as a whole. Only once a decision about double-weighting had been made, was the quality of the output, and if appropriate, the reserve output, assessed. Of the 18 outputs submitted with requests for double-weighting, 14 were judged to meet the criteria. Table 3 below provides a summary of double-weighting requests and outcomes by sub-panel.

Table 3: Double-weighting requests and outcomes

UOA	Name	Double-weightings requested	Double-weightings accepted
	Main Panel B	18	14
7	Earth Systems and Environmental Science	6	6
8	Chemistry	0	0
9	Physics	4	2
10	Mathematical Sciences	3	2
11	Computer Science and Informatics	4	3
12	Aeronautical, Mechanical, Chemical and Manufacturing Engineering	0	0
13	Electrical and Electronic Engineering, Metallurgy and Materials	0	0
14	Civil and Construction Engineering	0	0
15	General Engineering	1	1

Cross-referrals and work that spans UOA boundaries

29. Table 4 below provides a summary of the cross-referrals in and out of Main Panel B sub-panels, including a breakdown of cross-referrals within the main panel sub-panels and to/from other main panel sub-panels.

Table 4: Cross-referrals into and out of Main Panel B

UOA	Name	Cross-referrals out			Cross-referrals in		
		Within Main Panel	**Outside Main Panel**	**Total out**	**From Within Main Panel**	**From Outside Main Panel**	**Total in**
	Main Panel B	621	460	1,081	621	609	1,230
7	Earth Systems and Environmental Science	101	318	419	285	119	404
8	Chemistry	12	7	19	23	70	93
9	Physics	118	34	152	243	8	251
10	Mathematical Sciences	175	14	189	41	99	140
11	Computer Science and Informatics	0	25	25	12	119	131
12	Aeronautical, Mechanical, Chemical and Manufacturing Engineering	178	0	178	3	88	91
13	Electrical and Electronic Engineering, Metallurgy and Materials	27	30	57	6	24	30
14	Civil and Construction Engineering	0	1	1	7	52	59
15	General Engineering	10	31	41	1	30	31

30. Sub-panels in Main Panel B cross-referred a total of 1081 outputs to other sub-panels, comprising 2.2 per cent of the total outputs submitted. They accepted a similar number, 1230, of incoming requests from other sub-panels, covering a wide range of outputs falling within their remits.

31. The sub-panels were confident that their expertise was sufficient to assess the vast majority of the outputs received and cross-referrals were only requested when they were on or beyond the boundaries of their subject scope. In making these judgements, sub-panels took note of institutions' requests for sub-panels to consider cross-referral, but the decision on cross-referral rested with the sub-panel irrespective of whether such requests had been made or not. In a small number of cases, it appeared that institutions had chosen to structure their submissions in a way that required significant groups of outputs to be cross-referred to other panels.

32. More detailed discussion of cross-referral arrangements is included in sub-panel sections of this report, where appropriate.

Scoring schemes

Outputs

33. Each output was assessed against the criteria of originality, significance and rigour and given an integer score on the scale 0-4, corresponding to the starred level descriptors set out in Annex A of Assessment Framework and Guidance on Submissions. Sub-panels' working methods included mechanisms to identify outputs where the quality fell on the borderline between assessment scores, and to enable careful consideration of appropriate scores in these cases.

Impact

34. In developing the impact sub-profiles, all the sub-panels used the same method of assigning star levels to case studies and impact templates. Each case study and each impact template was graded on a nine point scale consisting of integer and half-integer scores from 0-4, with the integer scores corresponding to the starred level descriptors for the impact sub-profile. Half-integer scores of 0.5, 1.5, 2.5 or 3.5 were assigned to case studies and impact templates that were judged to be on the borderline between two of the starred levels.

35. A case study/template with a half-integer score contributed to the impact sub-profile by assigning half of its grade to each of the two starred levels that the borderline grade fell between. For example, if there were four case studies in the submission, each case study contributed 20 per cent to the impact sub-profile (the impact template contributed the remaining 20 per cent). If one of the case studies was graded as 3.5, it contributed 10 per cent at 4* and 10 per cent at 3* to the impact sub-profile.

Environment

36. In developing the environment sub-profiles, all the sub-panels used the same method of assigning star levels to the submitted material. Each section of the environment template was graded on a nine point scale consisting of integer and half-integer scores from 0-4, with the integer scores corresponding to the starred level descriptors for the environment sub-profile. Half-integer scores of 0.5, 1.5, 2.5, or 3.5 were assigned to sections of the environment template that were judged to be on the borderline between two of the starred levels.

37. A section of the environment template with a half-integer score contributed to the environment sub-profile by assigning half of its grade to each of the two starred levels that the borderline grade fell between. For example, in Main Panel B the strategy section was weighted as contributing 20 per cent to the environment sub-profile. A score of 2.5 for this section therefore contributed 10 per cent of 3* and 10 per cent of 2* to the sub-profile.

Overview of research outputs

38. Table 5 below gives the overall FTE volume weighted output sub-profiles for the main panel and each of its sub-panels. These results show an improvement in the quality of outputs compared with RAE2008. Sub-panels and the main panel consider that the quality of UK research in physical, computer and mathematical sciences and engineering has been stronger in the REF assessment period than it was during the equivalent assessment period for RAE2008, due to a number of factors such as investment by HEIs and improvement in output quality generally (an improvement supported by international comparative bibliometric data – www.ref.ac.uk/results/analysis/comparisonwith2008raeresults)

Table 5: FTE volume weighted sub-profiles for the main panel and sub-panels

UOA	Name	Average percentage of research activity judged to meet the standard for:				
		4*	**3***	**2***	**1***	**U**
	Main Panel B	20.1	61.4	16.7	1.5	0.3
7	Earth Systems and Environmental Science	18.2	60.7	18.9	2.0	0.2
8	Chemistry	22.1	69.4	8.1	0.2	0.2
9	Physics	21.3	66.6	11.3	0.5	0.3
10	Mathematical Sciences	22.7	59.7	16.8	0.6	0.2
11	Computer Science and Informatics	22.1	47.1	25.8	4.8	0.2
12	Aeronautical, Mechanical, Chemical and Manufacturing Engineering	18.0	60.4	20.7	0.8	0.1
13	Electrical and Electronic Engineering, Metallurgy and Materials	19.7	67.7	11.3	1.1	0.2
14	Civil and Construction Engineering	18.1	58.0	19.3	4.3	0.3
15	General Engineering	17.2	65.8	15.5	1.0	0.5

39. Many of the sub-panels were pleased to note an increase in the number of outputs arising from interdisciplinary research and from collaborative working across units within and across HEIs both in the UK and with international partners. Interdisciplinary work now represents a significant proportion of the outputs submitted to Main Panel B and sub-panels received many examples of excellent interdisciplinary research. As noted above in relation to cross-referrals, the sub-panels had appropriate membership and processes to enable them to assess robustly the majority of interdisciplinary work within the sub-panel to which it had been submitted. Cross-referral was however used when necessary.

40. HEIs were encouraged to allocate submitted staff and/or outputs to research groups within their submissions. For future exercises, the main panel recommends that consideration is given to making this mandatory rather than optional, to assist with the allocation of outputs for assessment and to enable more specific feedback to institutions on performance.

41. Citation data, provided from the Scopus database, were used by sub-panels 7, 8, 9 and 11. For sub-panels 7, 8 and 9, it was noted that there could be variability in the quality and usefulness of the data at sub-discipline level. As set out in the criteria document, for these sub-panels, panellists used their academic judgement to evaluate the outputs and only used citation data when appropriate to inform the assessment of the academic significance of outputs. Sub-panel 11 had initially advised that it would use Google Scholar data in addition to Scopus but, as announced

before the submission date, copyright constraints on Google Scholar data meant that with regret this proved not to be feasible. This sub-panel made some very limited use of the Scopus data.

42. Sub-panels 11, 12, 13, 14 and 15 made use of the information (100 words) that institutions were invited to submit about the significance of outputs, not evident from the output itself. Where used appropriately, this provided useful information that was very helpful in assessing the significance of outputs. However, these sub-panels were disappointed that not all institutions made effective use of this part of the submission and some HEIs actually used it in ways that were explicitly disallowed in the Main Panel B published guidance.

43. Sub-panel 9 collected information about author contribution for outputs with more than 10 co-authors. With larger numbers of co-authors becoming more prevalent across many Main Panel B disciplines, the main panel recommends that consideration be given to adopting a similar approach across all physical science and engineering disciplines for future exercises.

44. For review articles submitted as research outputs, the main panel’s criteria document invited the submission of textual commentary identifying the original research or new insights reported. This information was not provided for all review articles submitted. The main panel recommends that consideration be given to this requirement being mandatory for future exercises.

45. As noted in the section on Panel Working Methods, Main Panel B international members made important contributions to the assessment of outputs.

46. Table 6 below shows a breakdown of outputs types within each UOA, and for the main panel as a whole.

Table 6: Breakdown of types of outputs

	UOA		**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Type Code	**Output type**	**Main Panel B**	**Earth Systems and Environmental Science**	**Chemistry**	**Physics**	**Mathematical Sciences**	**Computer Science and Informatics**	**Aeronautical, Mechanical, Chemical and Manufacturing Engineering**	**Electrical and Electronic Engineering, Metallurgy and Materials**	**Civil and Construction Engineering**	**General Engineering**
A, B, C	**Books and book chapters**	335	46	1	5	84	149	11	3	12	24
D	**Journal article**	46,540	5,195	4,688	6,376	6,731	5,555	4,110	3,984	1,348	8,553
E	**Conference contribution**	2,099	4	2	17	17	1,902	24	28	16	89
U	**Working paper**	176	0	0	38	134	3	0	0	0	1

	UOA		7	8	9	10	11	12	13	14	15
Type Code	**Output type**	**Main Panel B**	**Earth Systems and Environmental Science**	**Chemistry**	**Physics**	**Mathematical Sciences**	**Computer Science and Informatics**	**Aeronautical, Mechanical, Chemical and Manufacturing Engineering**	**Electrical and Electronic Engineering, Metallurgy and Materials**	**Civil and Construction Engineering**	**General Engineering**
F	**Patent/ published patent application**	56	3	3	6	0	12	2	10	0	20
N,O	**Research reports**	39	2	0	4	0	11	6	1	7	8
G,H,Q,S	**Software, website content, research datasets**	27	0	4	0	8	12	0	2	1	0
I,J,K,L,M,P,R,T	**Other types**	45	0	0	0	21	21	1	0	0	2
	Grand total	**49,317**	**5,250**	**4,698**	**6,446**	**6,995**	**7,665**	**4,154**	**4,028**	**1,384**	**8,697**

Note: Where the sub-panel agreed a double-weighting these outputs count twice and where a reserve was not scored it is not included in these numbers.

Overview of impact

47. Table 7 below gives the overall FTE volume weighted impact sub-profiles for the main panel and each of its sub-panels. Sub-panels received many examples of outstanding impact. Sub-panels were pleased by the wide range of types of impact received, including impacts on the economy, public policy and services, society, culture and creativity, health, security, products, practitioners and professional services, and the environment. Across all sub-panels a number of case studies were submitted based on public engagement activity. The sub-panels were impressed by the high degree of reach and significance of many of the examples of impact submitted. Further comments on the ranges and types of impact are given in the sub-panel sections of this report.

Table 7: FTE volume weighted impact sub-profiles for the main panel and sub-panels

UOA	Name	Average percentage of research activity judged to meet the standard for:				
		4*	**3***	**2***	**1***	**U**

UOA	Name	Average percentage of research activity judged to meet the standard for:				
		4*	3*	2*	1*	U
	Main Panel B	37.8	45.7	13.3	2.3	0.9
7	Earth Systems and Environmental Science	36.2	53.8	9.1	0.4	0.5
8	Chemistry	39.6	52.6	7.5	0.3	0.0
9	Physics	37.0	46.5	15.2	1.1	0.2
10	Mathematical Sciences	35.9	46.6	14.1	2.3	1.1
11	Computer Science and Informatics	36.9	38.0	15.0	7.8	2.3
12	Aeronautical, Mechanical, Chemical and Manufacturing Engineering	38.4	47.0	13.9	0.7	0.0
13	Electrical and Electronic Engineering, Metallurgy and Materials	36.5	49.0	12.1	1.6	0.8
14	Civil and Construction Engineering	33.9	52.5	11.4	0.0	2.2
15	General Engineering	41.6	39.8	15.5	2.3	0.8

48. While some research was planned to produce the impacts reported in the case study, a significant proportion of impact was observed not to have been predicted or planned when the research was undertaken. The panel recognises that it is good to create an environment that supports and promotes impact, but considers that it is also important to continue to recognise that research can lead to unanticipated impacts.

49. Sub-panels were pleased that the arrangements for the submission of information relating to impact and the arrangements for its assessment enabled them to undertake robust assessment. They considered that case studies in the format required were an effective way of assessing impact, and that the volume of case studies relative to submitted FTEs was appropriate. They also considered that the 2* threshold for the quality of the underpinning research was appropriate, and it was notable that only a very small proportion of case studies were assessed as not meeting this threshold. With the exception of specific comments in the sub-panel reports for sub-panels 8 (Chemistry), 9 (Physics) and 10 (Mathematical Sciences), sub-panels feel that the 25 year period prior to the beginning of the assessment period for underpinning research was appropriate. Due to the nature of their disciplines, sub-panels 9 and 10 are of the view that a longer time period for underpinning research would be appropriate, while Sub-panel 8 would welcome a longer time period for impact in the pharmaceutical area.

50. In terms of the submitted case studies, sub-panels observed that the best case studies made a clear case for the links between the underpinning research and the impact claimed and

provided quantitative evidence of the reach and significance of the impact in the assessment period. Some case studies included a description of anticipated future impact, which was not eligible for assessment.

51. As described above**,** users of research played an important part in the assessment of impact in a number of ways at both main and sub-panel level.

52. In relation to the future assessment of impact, the main panel has the following observations:

- The information requested in the impact template would be more appropriately combined with the environment template; the panel expects impact to be embedded in research activity, underpinning all aspects of the research environment, and should not be artificially isolated as a separate enterprise.
- Notwithstanding this, the 20 per cent weighting for Impact is considered to be appropriate and should be retained, thereby slightly increasing the weighting on the impact case studies.
- The Funding Councils will need to give consideration to the approach to the submission of impact submitted to REF2014 that has continued through the next assessment period and where the underpinning research is still within the eligible period for inclusion of the impact.
- The submissions data suggest that some institutions may have limited the number of staff submitted to the REF in accordance with the number of case studies available to them. Approximately 30 per cent of submissions received to Main Panel B were within 1.0 FTE of the threshold for an additional case study. This may be something which needs to be considered in future exercises.

Overview of research environment

53. Table 8 below gives the overall FTE volume weighted environment sub-profiles for the main panel and each of its sub-panels. Overall the quality of the environment submissions presented was found to be high, with evidence that many units have exciting and stimulating environments in which to carry out research.

Table 8: FTE volume weighted environment sub-profiles for the main panel and sub-panels

		Average percentage of research activity judged to meet the standard for:				
UOA	**Name**	**4***	**3***	**2***	**1***	**U**
	Main Panel B	38.1	47.4	12.6	1.9	0.0
7	Earth Systems and Environmental Science	31.2	60.0	8.3	0.5	0.0
8	Chemistry	38.0	49.2	12.1	0.7	0.0
9	Physics	44.0	48.5	7.3	0.2	0.0
10	Mathematical Sciences	44.2	47.4	8.1	0.3	0.0
11	Computer Science and	27.4	42.5	23.5	6.5	0.1

UOA	Name	Average percentage of research activity judged to meet the standard for:				
		4*	3*	2*	1*	U
	Informatics					
12	Aeronautical, Mechanical, Chemical and Manufacturing Engineering	36.8	55.0	6.4	1.6	0.2
13	Electrical and Electronic Engineering, Metallurgy and Materials	30.7	53.7	13.9	1.7	0.0
14	Civil and Construction Engineering	35.1	56.5	7.9	0.5	0.0
15	General Engineering	46.5	34.9	16.4	2.2	0.0

54. Many submissions have detailed outstanding achievements since RAE2008 and some have well-articulated strategies with clear implementation plans. However, the sub-panels were disappointed that many strategies focused only on current practice and did not give the requested update on progress since RAE2008. Perhaps more importantly, a number also did not include specific goals in support of their strategic aims and details of how these would be taken forward.

55. There was clear evidence of investment in human capital, with significant numbers of early career researchers included in many submissions. Overall approximately 20 per cent of staff submitted to Main Panel B were early career researchers and this is encouraging for the continued vitality and sustainability of the physical, computer and mathematical sciences and engineering research base in the UK. Training and career development support, particularly for early career staff, appears to be much more widely embedded in staffing strategies and there was evidence of the implementation of the Concordat to support the career development of researchers.

56. Some institutions improved their outputs profile by the appointment on a 0.2 FTE basis of staff from elsewhere. In the view of the panel this tactic was considered non-sustainable and detrimental to the research environment.

57. The sub-panels noted that many submissions gave information on how they supported equality and diversity. There were a number of examples of best practice and notable examples of the achievement by units of diversity awards such as Athena SWAN. Some submissions did however focus on HEI wide policies and procedures, and the sub-panels wold have liked to have seen more about how these units were implementing them locally, and evidence of the benefits they had brought to the unit. The panel also considered that it is important to be aware that, although gender issues are very important in the science, technology, engineering and mathematics subjects, other forms of diversity and groups with protected characteristics also need to be supported.

58. Table 9 below gives a brief summary of the data submitted in the REF4a, 4b and 4c that was used to inform the assessment of the ‘People’ and ‘Income and Infrastructure’ sections of the Environment template.

Table 9: Summary of environment data for Main Panel B

UOA	Name	Category A and C staff head count	Category A Staff FTE	Total Doctoral Degrees Awarded in REF period	Total research income for REF period (£000)*
	Main Panel B	13,930	13,347	31,028	7,233,563
7	Earth Systems and Environmental Sciences	1,489	1,381	2,472	757,081
8	Chemistry	1,267	1,229	4,734	931,246
9	Physics	1,774	1,705	3,580	1,312,892
10	Mathematical Sciences	2,005	1,931	2,515	353,765
11	Computer Science and Informatics	2,159	2,045	4,174	789,752
12	Aeronautical, Mechanical, Chemical and Manufacturing Engineering	1,193	1,153	3,534	835,589
13	Electrical and Electronic Engineering, Metallurgy and Materials	1,113	1,071	3,742	811,943
14	Civil and Construction Engineering	418	391	829	173,350
15	General Engineering	2,555	2,447	5,448	1,267,944

**Notes:*

1. *Income figures have been adjusted to reflect 2012-13 prices; the 'deflators' used to adjust to base year 2012-13 are based on HM Treasury's gross domestic product deflator.*
2. *This table does not include income-in-kind from the BIS Research Councils.*

59. The rise in the volume of staff submitted has been accompanied by a significant increase in the number of postgraduate research students, as evidenced by a rise in the number of research doctoral degree awards of 23.5 per cent overall during the assessment period. Some sub-panels showed very marked increases. A feature during this period has been the expansion of doctoral training centres, including a number with industrial partners, as a model for the training of postgraduate research students. The sub-panels also noted there has been an increased emphasis on training in research methods and in transferable skills.

Table 10: Trend in research doctoral degrees awarded over the REF period

		Doctoral degrees awarded					**Change in degrees awarded 2008-09 to 2012-13**	**Percentage change in degrees awarded**
UOA	Name	**2008-09**	**2009-10**	**2010-11**	**2011-12**	**2012-13**		

		Doctoral degrees awarded						
UOA	Name	2008-09	2009-10	2010-11	2011-12	2012-13	Change in degrees awarded 2008-09 to	Percentage change in degrees awarded
	Main Panel B	5,550	6,113	6,204	6,304	6,856	13056	23.5%
7	Earth Systems and Environmental Sciences	448	485	463	469	607	159	35.4%
8	Chemistry	837	990	929	932	1,047	210	25.1%
9	Physics	633	690	730	749	779	147	23.2%
10	Mathematical Sciences	398	498	520	499	600	202	50.6%
11	Computer Science and Informatics	728	814	829	864	939	212	29.1%
12	Aeronautical, Mechanical, Chemical and Manufacturing Engineering	669	687	729	731	719	50	7.5%
13	Electrical and Electronic Engineering, Metallurgy and Materials	734	738	696	791	783	48.7	6.6%
14	Civil and Construction Engineering	145	163	155	176	190	45	30.7%
15	General Engineering	959	1,050	1,154	1,094	1,192	233	24.3%

60. Despite the difficult funding environment of the last six years, where the Research Council science budget has remained flat (and therefore reduced in real terms) and capital funding has been reduced, there is evidence of clear targeted investment in research infrastructure, with demonstrable benefits to research. Table 11 below shows that annual external research income as reported in the REF4b (excluding in-kind income from BIS Research Councils) has risen in real terms by 9.1 per cent over the period (using HM Treasury deflators to account for the effects of inflation). However, performance in terms of research income varies considerably across the Main Panel B sub-panels. In contrast, in-kind income from BIS Research Councils, as reported in REF 4c has fallen in real terms by 16 per cent (see Table 13).

Table 11: Trend in total external income by sub-panel over the REF period

		Total external research income (£000) in 2012-13 prices					Change in income 2008-09 to 2012-13 (£ 000s)	Percentage change in income 2008-09 to
UOA	Name	2008-09	2009-10	2010-11	2011-12	2012-13		
	Main Panel B	1,405,321	1,414,323	1,440,016	1,441,129	1,532,773	127,452	9.1%
7	Earth Systems and Environmental Sciences	138,902	149,602	151,699	153,943	162,934	24,032	17.3%
8	Chemistry	190,524	184,151	180,516	178,473	197,581	7,057	3.7%
9	Physics	270,282	268,575	260,894	252,712	260,429	-9,854	-3.6%
10	Mathematical Sciences	62,803	69,287	71,208	73,649	76,817	14,014	22.3%
11	Computer Science and Informatics	161,667	158,343	157,577	153,579	158,585	-3,082	-1.9%
12	Aeronautical, Mechanical, Chemical and Manufacturing Engineering	152,600	155,426	164,998	174,189	188,375	35,775	23.4%
13	Electrical and Electronic Engineering, Metallurgy and Materials	161,635	159,404	160,700	158,840	171,364	9,729	6.0%
14	Civil and Construction Engineering	33,967	34,235	35,870	33,630	35,649	1,682	5.0%
15	General Engineering	232,940	235,300	256,553	262,113	281,038	127,452	20.6%

Note: these figures have been adjusted to reflect 2012-13 prices; the 'deflators' used to adjust to base year 2012-13 are based on HM Treasury's gross domestic product deflator. This table does not include income-in-kind from the BIS Research Councils.

61. Figure 1 and Tables 12 and 13 show further breakdowns of external research income in Main Panel B as follows:

- Figure 1 shows the trend broken down by source of income over the RAE2008 and REF2014 periods, using data as reported by HEIs to the Higher Education Statistics Agency (HESA);
- Table 12 shows the trend by source in more detail for the REF period, using data reported to REF2014 in the REF4b form;
- Table 13 shows the total value of external funding during the REF period broken down by both sub-panel and by source, together with the percentage change between the first and last years of the REF assessment period.

Figure 1: Trend in external income for Main Panel B subjects reported to HESA by UK HEIs, by source, figures adjusted to 2012-13 prices

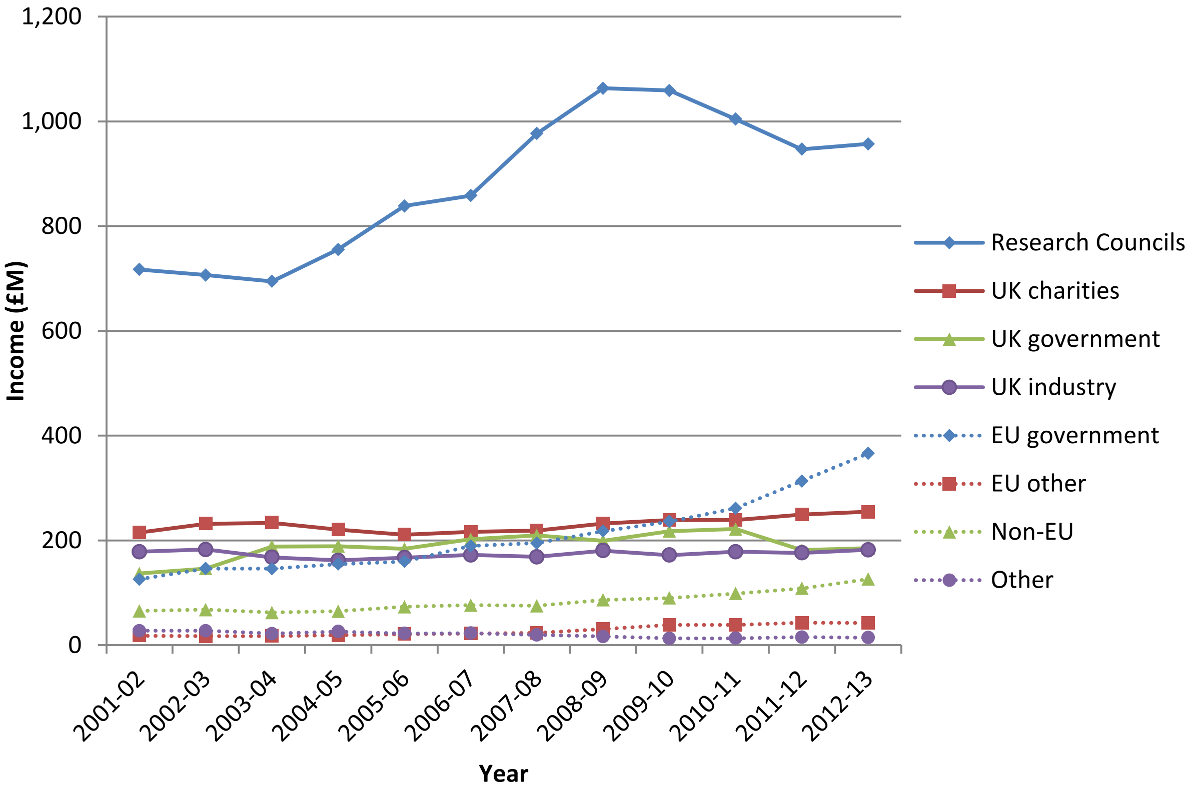

Table 12: Trend in total external income by funding source over the REF period

	Total external research income (£000) by funding source in 2012-13 prices					Change in income 2008-09 to 2012-13 (£ 000s)	Percentage change in income 2008-09 to 2012-13
	2008-09	**2009-10**	**2010-11**	**2011-12**	**2012-13**		
BIS Research	811,769	810,653	775,240	731,795	736,438	-75,331	-9.3%

	Total external research income (£000) by funding source in 2012-13 prices					Change in income 2008-09 to 2012-13 (£ 000s)	Percentage change in income 2008-09 to 2012-13
	2008-09	2009-10	2010-11	2011-12	2012-13		
Councils, Royal Society, British Academy and Royal Society of Edinburgh							
Income-in-kind from BIS Research Councils	308,881	320,478	309,011	294,243	259,394	-49,487	-16.0%
UK-based charities (open competitive process)	35,601	43,268	44,800	49,100	56,768	21,167	59.5%
UK-based charities (other)	7,539	6,483	5,482	6,947	7,609	70	0.9%
UK central government bodies, local authorities, health and hospital authorities	146,890	148,199	162,215	139,717	148,351	1,461	1.0%
UK industry, commerce and public corporations	142,057	132,048	141,914	146,062	153,855	11,798	8.3%
EU government bodies	170,929	178,244	207,026	252,367	294,184	123,255	72.1%
EU-based charities (open competitive process)	365	609	874	1,077	1,506	1,141	312.8%
EU industry, commerce and public corporations	13,365	17,523	18,413	22,572	20,474	7,108	53.2%
EU other	7,492	10,133	8,910	8,707	9,091	1,600	21.4%
Non-EU based charities (open competitive process)	9,779	4,791	5,399	4,905	6,098	-3,680	-37.6%
Non-EU industry,	31,814	34,438	39,182	44,284	58,472	26,658	83.8%

	Total external research income (£000) by funding source in 2012-13 prices					Change in income 2008-09 to 2012-13 (£ 000s)	Percentage change in income 2008-09 to 2012-13
	2008-09	**2009-10**	**2010-11**	**2011-12**	**2012-13**		
commerce and public corporations							
Non-EU other	17,232	18,971	22,660	25,928	29,345	12,113	70.3%
Other sources	10,490	8,962	7,901	7,667	10,582	92	0.9%

Note: these figures have been adjusted to reflect 2012-13 prices; the 'deflators' used to adjust to base year 2012-13 are based on HM Treasury's gross domestic product deflator.

Table 13: Total external income broken down by sub-panel and by source

	Total income in assessment period (£000) and % change from 2008-9 to 2012-13									
Funding source	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**MPB**
BIS Research Councils, Royal Society, British Academy and Royal Society of Edinburgh	396,123 -3.0%	546,753 -12.8%	1,011,358 -12.1%	234,103 3.0%	395,769 -12.4%	306,138 -8.6%	397,790 -6.5%	82,415 -3.3%	495,445 -10.2%	3,865,895 -9.3%
Income-in-kind from BIS Research Councils	85,347 -37.7%	118,238 -38.8%	1,181,178 -10.8%	160 108.9%	1,877 -15.4%	32,795 -29.6%	33,432 -34.3%	664 -19.7%	38,317 -19.2%	1,492,007 -16.0%
UK-based charities (open competitive process)	25,081 18.6%	63,949 35.5%	20,533 34.4%	16,987 14.2%	19,784 45.7%	14,400 53.0%	16,415 82.3%	2,592 43.1%	49,796 194.7%	229,537 59.5%
UK-based charities (other)	3,916 55.7%	4,639 -55.5%	2,684 72.7%	1,661 -62.5%	738 103.7%	6,450 16.5%	3,932 -71.8%	1,785 272.2%	8,257 63.2%	34,060 0.9%
UK central government bodies, local authorities, health and hospital authorities	81,254 0.3%	54,755 -28.1%	55,689 -1.1%	16,513 31.6%	73,081 -17.7%	125,621 40.2%	110,951 -12.0%	25,168 -27.4%	202,338 7.9%	745,372 1.0%
UK industry, commerce and public corporations	57,750 14.8%	65,211 -8.9%	28,939 0.8%	14,794 27.0%	48,365 -25.8%	176,086 11.9%	97,902 13.6%	27,158 32.5%	199,731 14.4%	715,936 8.3%
EU government bodies	119,688 108.8%	130,377 112.5%	146,182 60.7%	37,185 203.9%	210,002 19.4%	109,281 78.0%	131,686 56.3%	23,886 28.6%	194,462 108.7%	1,102,750 72.1%
EU-based charities (open competitive process)	1,136 141.0%	787 201.9%	366 -4.1%	139 654.8%	143 -89.2%	526 10034%	137 -	239 233.5%	958 440.8%	4,431 312.8%
EU industry, commerce and public	7,928	12,726	3,324	1,894	4,015	20,596	19,427	2,657	19,779	92,347

	Total income in assessment period (£000) and % change from 2008-9 to 2012-13									
Funding source	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**MPB**
corporations	290.6%	50.4%	84.3%	709.0%	13.4%	53.2%	23.1%	-44.2%	23.2%	53.2%
EU other	10,397 10.1%	2,604 -29.9%	7,335 -29.7%	1,966 -55.9%	4,612 1.6%	2,685 160.7%	5,524 5.1%	2,014 -4238%	7,197 156.8%	44,333 21.4%
Non-EU based charities (open competitive process)	4,012 -12.8%	6,897 -74.1%	2,761 41.0%	2,516 405.0%	2,042 -6.4%	3,865 -59.9%	715 -60.4%	187 -29.4%	7,977 -45.9%	30,972 37.6%
Non-EU industry, commerce and public corporations	28,609 10.2%	25,123 137.6%	10,453 -25.4%	2,663 14.2%	15,156 71.5%	56,020 203.3%	12,431 31.2%	1,665 12.1%	56,069 91.9%	208,190 83.8%
Non-EU other	12,700 111.9%	11,576 188.3%	18,285 63.8%	22,420 50.9%	9,534 157.3%	9,696 58.0%	10,778 40.2%	2,142 40.3%	17,006 35.4%	114,136 70.3%
Other sources	8,488 52.9%	5,849 -36.5%	4,984 -50.5%	923 -8.8%	6,511 96.7%	4,225 -17.4%	4,255 -39.8%	1,442 -28.9%	8,928 14.5%	45,602 0.9%

Note: these figures have been adjusted to reflect 2012-13 prices; the 'deflators' used to adjust to base year 2012-13 are based on HM Treasury's gross domestic product deflator.

62. These data demonstrate that the BIS Research Councils remain the largest and most important source of funding for UK research for all Main Panel B sub-panels. However, annual funding from the Research Councils has fallen by over 9 per cent in real terms over the assessment period and HEIs are clearly diversifying the sources of their funding with a significant proportion of funding in all sub-panels now sourced from UK and EU government bodies and UK and international industry.

63. All sub-panels demonstrated a significant increase in funding from EU and non-EU sources, demonstrating the growing internationalisation of the UK's science, technology and engineering research activity. Significantly, all of the engineering sub-panels demonstrated an increase in funding from industry over the REF assessment period with a large percentage growth in funding from non-EU industry. While this is valuable funding for institutions it does raise concern about jeopardising the ability to achieve economic impact from the research within the UK.

64. Sub-panels reported an increase in interdisciplinary working and more collaborative research, both within academia and with external partners. Industrial involvement and take-up is healthy in the engineering disciplines. UK science is benefitting from major international collaborations and access to national and international facilities.

Sub-panel reports

65. Detailed subject-specific comments from the nine sub-panels of Main Panel B follow.

UOA 7: Earth Systems and Environmental Sciences

Summary of Submissions

UOA	Earth Systems and Environmental Science		
	2014	**2008**	**% difference**
Number of submissions	45	42	+7.1%
Category A staff FTE	1,381	1,179	+17.1%
Category A and C staff headcount	1,489	1,280	+16.3%
Number of outputs	5,250	5,091	+3.1%
Outputs per Category A and C staff headcount	3.53		
Impact case studies	175	-	

	% 4*	**% 3***	**% 2***	**% 1***	**% u/c**
Overall	**24**	**59**	**15**	**2**	**0**
Outputs	18.2	60.7	18.9	2.0	0.2
Impact	36.2	53.8	9.1	0.4	0.5
Environment	31.2	60.0	8.3	0.5	0

1. Unit of Assessment 7 received 45 submissions, comprising a headcount of 1489 Category A and C individuals; Category A staff FTE totalled 1381. In 2008, 42 submissions were received by the Earth Systems and Environmental Sciences panel (panel 17) with 1280 FTE Category A and C individuals. Although there has been a slight increase in the number of institutions making submissions to UOA 7, there has been a significant increase in the number of individuals being submitted. This suggests an expansion in the depth and breadth of the field, with some institutions making larger submissions. The average change in size for the 34 HEIs that had submitted to the Earth Systems and Environmental Sciences panel in 2008 was an increase of 3 FTE (standard deviation 9 FTE).

2. As noted in previous research assessment exercises, the scientific understanding of the Earth and the environment is literally of global significance. As such, it is the subject of fundamental research that generates applications of immense value to a very wide variety of economically and socially vital industries, as well as providing essential information to guide governments and policy

formers, but it also gives insights into our planet that are deeply fascinating to the public and the media. The health of Earth Systems and Environmental Sciences research in our universities is therefore essential to the well-being and success of the UK as whole.

3. Many of the trends in the sector detected in the RAE2008 have continued, both with changes in the academic structure of UK universities, but also from the increasing benefits seen from the investments made in infrastructure to support excellent research in Earth Systems and Environmental Sciences. Many academic departments in this area are now much more multi-disciplinary than they were historically, and the submissions included research that ranged from Environmental Public Health, Geography, Plant Science, Zoology, Ecology and Environmental Chemistry through to Meteorology, Oceanography, Geology, Geophysics, Geochemistry, and Geobiology to Planetary Astronomy and Archaeology. Sub-panel (SP) 7 was involved with many out-going cross-referrals with most going to the Geography sub-panel. At least one substantial submission was cross-referred into SP 7 from another sub-panel, and some Environmental Science submitted to other cognate sub-panels was cross-referred into SP 7.

4. It is the sub-panel's impression that the overall state of the UK Earth Systems and Environmental Science research base is very strong indeed, and that the investment in staff and infrastructure in this area over the assessment period has paid dividends, in the quality of the outputs published, but also in the significance and importance of the impacts generated. It is the sub-panel's expectation that as a discipline UK Earth Systems and Environmental Sciences can continue to be world-leading, as long as internationally competitive investments in infrastructure and support are sustained. If they are, then there can be no doubt that not only will the UK economy benefit further (as it has already from the impacts from past research), but that UK and global society will benefit too, as UK HEI scientists are working on the major environmental challenges that face this generation and which will also face generations yet to come.

Outputs

5. As had also been found in RAE2008, the sub-panel noted that the overall quality of research outputs from this review exercise had improved relative to the previous exercise, with a marked increase in the proportion of outputs of international standard compared to outputs of national standard. The vast majority of outputs were judged to be of high international calibre (78.9 per cent 4* and 3*) with 18.2 per cent assessed as world-leading (4*). A large majority of institutions presented evidence that they are carrying out some world-leading science, with clusters of internationally competitive groups. In a number of institutions there is, however, a world-leading presence across a very broad spectrum of Earth Systems and Environmental Sciences, and there can be no doubt that the UK has a number of internationally significant centres of scholarly excellence in these disciplines. This continued improvement of the output profiles of UK HEIs may reflect the response of the community to RAE2008, significant new investment in infrastructure during the assessment period, or in some cases very selective REF staff submission criteria. However, some institutions improved their outputs profile by the appointment on a 0.2 FTE basis of established or recently retired staff from elsewhere. This tactic was considered by the sub-panel as non-sustainable, and it was felt that such behaviour would not help the discipline in the long run.

6. Within the wide spectrum of Earth Systems and Environmental Sciences, there are a number of sub-discipline themes to comment upon:

a. In geoscience (geology, geophysics, geochemistry, geobiology and mineralogy) the sub-panel noted that there was a strong and active research base over many HEIs across the UK. There was very impressive work being done in large-scale tectonics and seismology, and since RAE2008 there had been a significant increase in the amount of world-class volcanology, much underpinned by technological advances in seismology and geochemistry, and driven by the need to be able to predict events. Leading research on the geochemistry of igneous rocks has moved to micro-analytical research focusing on timescales, kinetics and diffusion, with a similar move in low temperature geochemistry and mineralogy. While past strengths such as metamorphic petrology and experimental petrology are becoming rarer, ultra-high pressure research on deep Earth materials, linked with planetary seismology and theoretical mineral physics, is world-leading. Overall, the benefits of technology are very apparent. Geophysics outputs were particularly strong and more widely distributed across HEIs than previously. Other geoscience strengths included marine geology, geohazards, and Earth observation. Palaeontology remains strong in some HEIs, but is less widely spread than previously and overall there is an increasing emphasis on vertebrate palaeontology. Palaeoceanography and palaeoclimatology research is widespread, often multi-disciplinary, and very highly graded, but depends on access to technology, collaborative data and exploration teams such as the International Ocean Drilling Program. The overall quality of interdisciplinary geoscience research work has improved since RAE2008 with, for example, increasing links between geoscience and ecology. In contrast, hydrogeology appears to be in decline and there is concern at the apparent loss of national expertise, though we note that some work may not have been submitted or referred to SP 7.

b. In the ocean science sub-discipline the sub-panel felt that there had been a marked increase in the quality of research submitted relative to RAE2008. This was driven in part by recent investments in very expensive infrastructure (e.g. two major NERC ships in the last 8 years), as well as new buildings, analytical equipment (including micro-sensor technology), and high-performance computing. The improvement was also driven by enhanced collaboration, both nationally (e.g. in Ocean Acidification and RAPID) and internationally, where the UK plays a major part in big field projects such as the Atlantic Meridional Transect, the Surface Ocean - Lower Atmosphere Study, Crozet, and International Ocean Discovery Program and in international organisations such as the Scientific Committee on Oceanic Research and the International Geosphere-Biosphere Programme. Research in ocean science is making major contributions in the basic disciplines and across diverse fields (e.g. offshore hydrocarbons and energy; atmospheric O_3 and halocarbons; plastics in the ocean; exploring the deep; and public engagement). HEIs are working well with the large UK research institutes. Particular strengths lie in climate and climate related research (underpinned by long time series studies), marine biogeochemistry, biology, geophysics, and palaeoceanography/climatology, but concerns exist over physical oceanography and marine analytical chemistry.

c. In the sub-discipline of atmospheric science, the overall volume of submitted research has increased since the last exercise. Output quality remains high. Areas of particular strength included palaeoclimate, carbon cycle and aerosol science, and there has been notable growth in areas of organic aerosols and geoengineering. There was, however, a smaller proportion in this assessment than in those of the past of high quality outputs in traditional areas such as weather systems and atmospheric dynamics. Multi-author large-scale international collaborative papers in support of, for example, the Intergovernmental

Panel on Climate Change process, were often highly cited. The panel noted the overall high volume of numerical modelling studies, which however needs to be balanced in the future by appropriate observational science if the long-term health of the sub-discipline is to be maintained. Such areas include instrument developments (both in situ and remote sensing), field campaigns, laboratory measurements and observations required to support the maintenance of long-term datasets.

d. In the sub-discipline of ecology, the sub-panel received many more submissions than previously, including from disciplines like whole-organism biology and microbiology, which were previously submitted to other panels. This is a reflection of how the environmental sciences and academic departments are now becoming much more interdisciplinary and that single disciplinary studies continue to be important. Again it is felt that investment in infrastructure and resources has led UK universities into a globally competitive position. Soil ecology and microbial ecology are developing well, integrated into biogeochemistry, often related to agriculture and biological sciences. This is healthy and such multidisciplinarity should be encouraged.

Impact

7. The sub-panel was particularly impressed by the quality and diversity of the impact presented, 90 per cent of which was judged to be outstanding or very considerable. Many case studies showed very significant contributions to the UK economy, while there were also numerous excellent examples of impact on environmental protection, understanding climate change, and public policy development, as well as those that showed significant public engagement or that resulted in significant media productions. There was very clear evidence of research that was 'blue skies' at the point of funding but that later yielded very strong impact focused on real world problems, despite impact not having been a HEFCE requirement at the time the research programmes were developed or were published. That unexpected outstanding and very considerable impacts resulted, often many years later, from 'blue skies' research programmes was very clear.

8. The geoscience impact case studies were exceptionally strong with many delivering significant financial benefits, especially in the resource and the hazard sectors. There were some excellent impact case studies in the atmospheric science areas, reflecting the long-term engagement of this research community with users and with policy makers (e.g. Intergovernmental Panel on Climate Change, and in air quality and ozone assessments). A particularly good recent example of fast-response impact from atmospheric scientists relates to the Icelandic volcano in 2010, and its lasting impact on the management of airspace. There were a number of excellent but distinct case studies on this event. Major impacts from ocean research were prominent in influencing public policy in coastal flooding, and in the development of climate, pollution and habitat directives. There were major strengths in impact case studies in microbial ecology, marine ecology, conservation biology and land management. New technologies are serving the atmospheric science research community well but many are being taken through to commercialisation outside of the UK (even though the underlying research is often based in the UK). Where there has been investment in community infrastructure and facilities (e.g. Facility for Airborne Atmospheric Measurements, Chilbolton Radar, research ships, supercomputers) high quality science and impact is being produced. It is important that this type of investment is maintained.

Research Environment

9. There was a great deal of international collaboration and overall the sub-panel was of the view that the UK Earth Systems and Environmental Sciences research base was of very high quality and internationally held in high esteem. Being internationally leading triggers a virtuous circle, as international researchers are increasing drawn to the leading UK Earth Systems and Environmental Sciences HEIs, which in turn increases their international competitiveness. The number of international authors and co-authors on the outputs seen by the sub-panel was significant.

10. The overall assessment of the quality of research within the UOA 7 submissions is consistent with recent metrics analysis showing the high international standing of UK Environmental Sciences (see: 'International Comparative Performance of the UK Research Base – 2013: A report prepared by Elsevier for the UK's Department of Business, Innovation and Skills (BIS)'). This study shows that UK Environmental Sciences has the highest field-weighted citation impact of all the sub-disciplines considered, and that it has strengthened significantly between 2008 and 2012.

11. There are generally positive signs on the focus universities have expressed on developing and supporting early career researchers, widening diversity, engaging with Athena SWAN and enhancing PhD student training. The sub-panel noted the pattern of concentration of Research Councils UK (RCUK) PhD funding into a restricted number of institutions and consortia as a significant recent change.

12. Although adequate research income is necessary for a unit to produce internationally significant research, it did not follow that large income was correlated with a high standing in research.

13. The sub-panel noted that a number of specialist areas were less prominent in the REF submissions than in previous submissions (e.g. metamorphic petrology, mineralogy, structural geology, hydrogeology, biostratigraphy, physical oceanography, marine analytical chemistry) and seem to be dropping out of the UK university research agenda. The UK economy relies heavily on well-qualified and trained research scientists. These trends are therefore particularly concerning since many of these specialties remain essential for industry, income generation and economic growth, and for ensuring that the next generation of the workforce is suitably skilled.

14. The size of the submissions to UOA 7 varied very considerably. The units with over 80 per cent of research graded as being internationally excellent or world-leading generally ranged in size from 20 to 80 FTE, but it was not axiomatic that the research of a large unit would be of the highest quality. A coherent environment and associated infrastructure were important factors in research quality, but with widespread variation in specialties and collaborations, many moderate and medium-sized units performed just as highly as much larger units. A small number of universities were in the position to establish an effective collaboration with a non-HEI research institute, which had a very positive overall effect on the research they submitted.

UOA 8: Chemistry

Summary of submissions

UOA	Chemistry		
	2014	**2008**	**% difference**
Number of submissions	37	33	+12.1%
Category A staff FTE	1,229	1,151	+6.8%
Category A and C staff headcount	1,267	1,233	+2.8%
Number of outputs	4,698	4,930	-4.7%
Outputs per Category A and C staff headcount	3.71		
Impact case studies	152	-	

Category A FTE Volume weighted profiles for UOA 8					
Profile Type	**% 4***	**% 3***	**% 2***	**% 1***	**% U**
Overall	**28**	**63**	**9**	**0**	**0**
Output	22.1	69.4	8.1	0.2	0.2
Impact	39.6	52.6	7.5	0.3	0.0
Environment	38.0	49.2	12.1	0.7	0.0

1. The submissions to UOA 8 showed the success of UK Chemistry during the assessment period with a very significant strengthening since RAE2008. There was a welcome increase in the number of submissions to the UOA: four more than made to RAE2008, with an overall increase in FTE of staff submitted of 6.8 per cent. The submissions contained many examples of research of world-leading quality; while the impact component clearly demonstrated and exemplified the substantial reach and significance of research in Chemistry for the economy and society.

2. The submission showed the wide range of the current discipline and its key role in interdisciplinary areas involving interactions with biomedical, materials and environmental sciences and with physics. This strength in interdisciplinarity is fostered by the health of core areas of the discipline. It was also evident from the submission that the discipline is also vital for a wide range of economic activity and is of crucial importance to many areas of manufacturing industry, as well as to environmental and societal well-being.

3. The discipline has seen much needed investments in infrastructure and staffing, which are promoting the excellence and international competitiveness of UK Chemistry. Of particular note is

the large number of appointments of early career staff, which was apparent from the submission. This influx of talented individuals will play a major role in sustaining and developing the strength and health of the discipline.

4. UK Chemistry has responded well to the challenges of the funding environment, by diversifying funding sources, including a substantial increase in EU based support. The real terms decline in support from RCUK sources is, however, a matter of considerable concern and the strength of the discipline as evidenced by the submission will require adequate levels of funding to maintain and further develop its high international profile.

5. Overall, the sub-panel considered that the submission demonstrated clearly the success and vitality of the discipline during the assessment period and showed its crucial role in the UK economy and society.

Outputs

6. The sub-panel noted a very high quality of outputs submitted. Despite the overall increase in the staff FTE submitted compared with RAE2008, there has been a drop in the number of outputs submitted of 4.7 per cent, indicating that HEIs have been more selective in their submissions and have taken greater advantage of the arrangements concerning individual staff circumstances that allow a reduction in the number of outputs to be submitted. Compared with RAE2008, the quality of the UOA as a whole has improved significantly, reflecting the general strengthening and investment in the discipline over the recent years; although the greater selectivity in some submissions may have contributed. The percentage of 4* outputs increased by 7 per cent to 22.1 per cent, while the decline in the proportion of 2* outputs, from 38.7 per cent to 8.1 per cent was particularly pronounced.

7. A further notable trend was the growth in the number of 'duplicate' outputs, i.e. outputs which were submitted by more than one institution, of which 264 were submitted to UOA 8. This trend is at least in part attributable to the growth of collaborative work discussed below.

8. The sub-panel highlighted particular strengths in chemical biology, materials chemistry, catalytic science, nanoscience, computational chemistry, synthetic organic chemistry, supra-molecular chemistry and magnetic resonance spectroscopy. It is important, however, to note that these and other areas of strength identified are built on an exceptional strength in the UK of the underpinning fundamental core areas of the discipline as evidenced by the submitted outputs.

9. As noted, synthetic organic chemistry remains strong, although, as expected, there were fewer outputs in the area, owing to the growth in chemical biology and medicinal chemistry. It is essential, however, that the core strength in synthesis is maintained as this underpins and is critical to high quality outputs in several other, including interdisciplinary, fields. The area of green' (sustainable) chemistry is growing rapidly, which it is anticipated will continue in the future.

10. The submissions made to the UOA also included many world-leading outputs in experimental physical chemistry, including work in reaction dynamics and photophysics, but the sub-panel was concerned that the cost of undertaking internationally leading work is eroding UK competitiveness in some areas of this sub-discipline.

11. The sub-panel noted that few papers were defined as analytical chemistry, with the majority in this field relating to applications rather than technique development.

12. The submission was clearly strengthened by a large component of collaborative work with national and international partners and the proportion of the submission based on such collaborations had grown during the assessment period. The sub-panel did, however, also note that some outstanding outputs were the work of single research groups. The submission also demonstrated the strong and continuing growth in interdisciplinary science in the submitted units, although many of these remain rooted in and reliant on fundamental chemistry; moreover, chemistry is in many cases clearly the lead discipline that is driving the research agenda. Evidence for these changes is apparent in the number of multi-author papers from large teams, which in many cases resulted in high impact papers using a large number of complementary techniques.

13. In assessing the outputs, although the sub-panel made appropriate use of citation data as one element in the determination of the significance of the output, peer review of the outputs was nevertheless critical to the process. The sub-panel assessed the quality of the submitted outputs without consideration of individual author contribution and would recommend this approach in future assessment exercises. The sub-panel did not request additional information describing the significance of the outputs which was not considered to be useful for this UOA. A small number of outputs were submitted which were predominantly reviews with little original research for which only low scores could be awarded. A small number were unclassified, including two which had been submitted to both RAE2008 and REF2014.

14. Overall the sub-panel considered that the outputs submitted showed a high degree of originality, significance and rigour and demonstrated the health and international competitiveness of UK Chemistry.

Impact

15. A broad range of impact was submitted, across a number of areas, including economic, environmental, health, social, policy, and public engagement. The sub-panel confirmed that the inclusion of impact in the REF exercise was a very positive development, allowing the discipline to demonstrate much of the reach and significance achieved by UK Chemistry over the last 20 years. The sub-panel, however, considered that there was an even broader range of impacts which had not been captured by the REF criteria, much of which arises from creating capability in the subject that will attract inward investment from other countries. In this context a major contribution to impact is in the training of research students who use their skills to benefit the economy and society in a wide range of different professions – an aspect that is not recognised within the current REF criteria.

16. Amongst the wide range of impact case studies submitted, the sub-panel noted the following features:

   a. Economic impact was strongly and clearly exemplified. Research in the discipline is clearly vital for several sectors of UK industry, Chemical biology and organic chemistry have major impacts in the pharmaceuticals sector, while catalytic and materials chemistry provided essential underpinning support for much of the manufacturing sector. The submission also showed the rapid growth in several of these areas of impact which is expected to accelerate in the next assessment period.

   b. Several case studies showed direct impact upon health and clinical practice, including diagnostics and treatment.

   c. There were a number of strong impacts in the area of environmental science, particularly relating to air quality.

d. Societal impact was noted in case studies relating to conservation of heritage where fundamental chemical research was playing an essential role.

e. Several case studies demonstrated highly effective outreach and public engagement helping to promote and exemplify the key role in current society of chemistry in particular and physical sciences in general.

f. Impacts in public policy were noted including, for example, in the development of measures to control atmospheric ozone depleting substances.

17. Many notable and high quality impacts arose from fundamental or ‘blue skies’ underpinning research; and in many strong case studies it was clear that there had not been a linear path from research to impact, despite the dependency of the impact on the underpinning research. This feature was marked in a number of the more transformational, ‘disruptive’ impacts. The sub-panel also noted that several strong impacts were based on underpinning interdisciplinary research in which Chemistry was a core component.

18. A number of the impact templates showed a shift in the approach to impact from a purely transactional relationship with third parties to a more strategic engagement. A number of templates also demonstrated investment in resources to manage and develop impact which had clearly been beneficial.

19. Several case studies contained excellent evidence in depth of the impact achieved, but in a number of cases the evidence provided to corroborate claims of impact was insufficient. However, the sub-panel did note the difficulty of obtaining corroborating evidence from some industrial and government sources. Many templates and case studies were very well and clearly written, allowing a full assessment of the impact achieved; but in a small number of templates and case studies, poorer presentation with failure to provide the requested information limited the scores that could be given. There is clearly a need in a number of cases for HEIs to be given more guidance about how to write a successful template and case study.

20. The sub-panel considered that both the 20 per cent weighting of impact and the number of case studies requested from submitting institutions was appropriate. The sub-panel also considered that the assessment process benefited hugely from the contribution of the impact assessors and the main panel user members.

21. Overall the sub-panel considered that the impact submissions had exemplified the very extensive and wide ranging reach and significance of the impact of research in Chemistry from the submitting institutions over recent years.

Research environment

22. After a steady decline in the number of submissions in recent exercises, due to closures of UK chemistry departments, it was pleasing to note an increase in the number of submissions to REF2014 and the re-opening of some departments.

23. The sub-panel noted many strong and coherent overall strategies for research in the submitting units, although in a number of cases, the strategies presented needed a sharper delineation between the description of achievements against the RAE2008 objectives and the forward looking strategy. The high level of collaboration evident, as noted above in the output submissions was a significant strength across the UOA as a whole.

24. In the ‘people’ component of the submissions, the sub-panel was pleased to observe that the great majority of submissions had strengthened their staff complement over the assessment period. The large number of early career researchers was a very positive sign for the health of the discipline and most submissions reported good mechanisms for their support and career development.

25. Overall, the discipline has seen a real terms decline in the level of funding from RCUK sources which has been partially compensated by diversification of funding sources with increases in funding gained from the EU. The sub-panel noted, however, that many HEIs have seen growth in their research income over the period, and a considerable amount of institutional investment was apparent, possibly due in part to the increasing requirements for institutional matched funding in bids to funding agencies, but also indicating the commitment of institutions to the discipline. However, there were large variations in income per FTE and a somewhat polarised income landscape; and the decline in RCUK support is a considerable concern for the future competitiveness of the discipline. The evaluation of infrastructure could have been assisted in some cases by the presentation of more detailed evidence.

26. The submission showed the extensive and effective use made by the UK chemistry community of both experimental and computational central facilities, which are clearly supporting a broad programme of high quality chemistry. The work supported covers the full range of the discipline from its interactions with physics and materials to biology, as well as core chemistry

27. The data requested on PhD enrolments were important and were used in the assessment. The sub-panel was pleased to note that PhD numbers had increased in many submitting units. Overall the submission showed a very healthy increase of 25 per cent in graduating PhD numbers over the assessment period. Most submissions reported good mechanisms for the training and development of PhD students.

28. Diversity awards were mentioned by many submissions, with Athena SWAN at bronze very prominent; the sub-panel anticipated progression to silver and gold for next REF exercise. The best submissions, however, described how they supported diversity rather than just listing their awards.

29. The sub-panel noted that a number of submissions were strengthened by evidence of extensive and effective networks of collaborations, both national and international, with both academic and industrial partners.

30. Overall the sub-panel considered that the environment component demonstrated the very considerable, and in many cases outstanding vitality and sustainability of Chemistry in the UK.

UOA 9: Physics

Summary of submissions and results

Submissions

	2014	2008	% difference
Number of submissions	41	42	-2.4%
Category A staff FTE	1,705	1,686	+1.1%
Category A and C staff headcount	1,774	1,793	-1.1%
Number of outputs	6,446	7,156	-9.9%
Outputs per Category A and C staff headcount	3.63		
Impact case studies	203	-	

Results

	Average percentage (Category A FTE weighted) judged to meet the standard for:				
	4*	**3***	**2***	**1***	**UC**
Overall	28	60	11	1	0
Output	21.3	66.6	11.3	0.5	0.3
Impact	37.0	46.5	15.2	1.1	0.2
Environment	44.0	48.5	7.3	0.2	0

1. The table above provides a summary of the submissions made to the sub-panel compared with submissions to RAE20008. This shows that while the number of institutions and overall volume of staff submitted are almost unchanged from RAE2008, the volume of outputs submitted has reduced by nearly 10 per cent. This is attributed to the greater use of the arrangements for the submission of staff with individual staff circumstances to REF compared with RAE2008. Although some departments have closed since RAE2008, the sub-panel was pleased to note that new ones have opened and that some of these have made submissions to REF.

2. Overall, the sub-panel considered that the REF exercise showed that the health of physics in the UK is very good. There is a very marked improvement in the standard of outputs compared to RAE2008, with very few outputs scoring below the 3* (internationally excellent) level. This represents a real improvement in quality. The best outputs often made use of strong collaborative interactions inside and outside the UK – a defining characteristic of the subject, which is almost entirely international in scope and outlook. The award of Nobel prizes for graphene (Geim and Novoselov) and for the discovery of the Higgs boson (Higgs) testify to the international strength of

the subject in both ‘small’ and ‘big’ science. This is also evident from the huge fraction of submitted outputs published in journals that have very small acceptance fractions, such as Nature and Physical Review Letters. The impact resulting from underpinning research in physics is very high across the board, from industrial product development through policy to public outreach. Some aspects of the environment provided by our physics units generate world-class research.

3. A great deal of physics is carried out in an interdisciplinary environment. This has increased since RAE2008. Work in physics is always undertaken in an international context, so that physicists have a very clear perception of the nature of international-standard and world-leading research.

4. It is a characteristic of physics in the UK that there is world-leading research and impact in almost all units regardless of size. The efforts being made to put in place environments conducive to sustaining world-leading research and its exploitation provide a springboard for future success.

Outputs

5. Detailed examination of more than 6,000 outputs across the entire subject gave the sub-panel a rare opportunity to gain a deep perspective into the state of physics research in the UK over the REF assessment period. In terms of subject sub-groupings, the sub-panel observed the following (in no particular order):

a. Astronomy has seen the emergence of exoplanetary astronomy with a leading UK contribution; there is continued excellence in cosmic microwave background studies and simulation of the evolution of the universe; asteroseismology and solar system research remains strong; space instrumentation is an area of UK leadership.

b. Particle physics is at an extraordinarily exciting stage with the discovery of the Higgs boson and increasing insight into the nature of neutrinos – UK scientists have leading roles in international collaborations with a frequency well beyond expectations from the decreasing resources available to them. Particle theory research in the UK continues to rank alongside the world leaders.

c. Nuclear physics had a smaller share of world-leading outputs compared with other areas. This may be due to the failure of the UK to invest in major international facilities in the last 20 years, thus reducing the scope of UK research and influence in this field. There is concern that the small number of theoretical nuclear physicists is sub-critical and that this weakens the theoretical underpinning of the subject.

d. Accelerator physics has expanded greatly since RAE2008. Although some excellent outputs were submitted, a considerable number of outputs in this field contained a significant element of previously published results.

e. There has been a large growth in plasma physics since RAE2008. Plasma physics is no longer seen as a ‘Cinderella’ subject and outputs across this field were rated highly.

f. This is a golden age for condensed matter physics, with exciting advances in heavy fermions, organic and hybrid semiconductors, topological insulators, nanoscience, metamaterials, etc. The UK is a leading partner in huge international efforts in these and related areas. The strength noted at RAE2008 in quantum phenomena has been maintained, and some of the best work in the world has been carried out in quantum information. Some sub-fields have seen a resurgence of activity (such as experimental studies of correlated oxides) in response to new technological challenges. Some fields have been given new impetus, e.g. two-dimensional materials related to graphene. The amount of activity in more traditional hard condensed matter appears reduced.

g. Theoretical studies in quantum condensed matter in the UK continue to be strong across a wide range, from cold atomic systems to materials modelling.

h. Photonics has produced world-leading work in sources, detectors and applications, including those in biophotonics. Growing numbers of researchers in the areas of cold atoms and quantum optics are leading the UK activity in quantum technologies. The UK is at the international forefront in both photonics theory and experiment.

i. There has been a significant growth in work on energy technologies, particularly photovoltaics based mainly on large-area organic and hybrid semiconductors and high efficiency III-V devices.

j. Soft matter (including the field of plastic electronics), complexity and biological physics are growing in importance in physics departments and were assessed very positively. These areas have been strengthened by increasing numbers of theorists moving into the field.

k. There continues to be a large and vital activity in climate science and related areas. While some of this work has been submitted to Physics, the sub-panel is aware of a significant amount of work underpinned by physics which has been submitted to other sub-panels.

6. A growing fraction of experimental physics can only be carried out by large international teams, leading inevitably to publications with a large number of authors. Since this has been true for many years in experimental particle physics, the sub-panel realised the need to put in place a system to ensure that all authors submitting an output with more than 10 authors specified their contribution in a rubric of up to 100 words. Once the sub-panel had determined that the rubric described a substantial and distinctive contribution, then the output was assessed as a whole, irrespective of the author's individual contribution. Since outputs with large numbers of authors are becoming increasingly common in other subjects, the sub-panel was strongly of the opinion that it would be desirable that any future REF exercise should have a uniform approach to this problem, at least in the physical and engineering sciences.

7. The sub-panel cross-referred outputs out as appropriate, the main subject areas being climate science (referred to Sub-panel 7, Earth Systems and Environmental Science), and string theory (referred to Sub-panel 10. Mathematical Sciences). In addition, some outputs (for example on gene expression) were referred to Sub-panel 5, Biological Sciences and some, mainly on molecular modelling were referred to Sub-panel 8, Chemistry. The sub-panel received incoming cross-referrals from a number of sub-panels, the largest volume being from Sub-panel 10, especially in aspects of astrophysics, cosmology, theoretical particle physics, condensed matter physics and magnetohydrodynamics. A significant number of papers in astrophysics and some in atomic and molecular physics and surface science were referred from Sub-panel 7. Small numbers of outputs were received from a diverse range of fields, ranging from health (Sub-panel 3, Allied Health Professions, Dentistry, Nursing and Pharmacy) to music (Sub-panel 35, Music, Drama, Dance and Performing Arts) and theology (Sub-panel 33, Theology and Religious Studies).

Impact

8. The sub-panel considered that impact reported in case studies could be consistently assessed and that physics has demonstrated very considerable impact across a wide range of domains including industrial, policy and public outreach. Much of this impact has clearly been outstanding and gives a clear picture of physics making an impressive contribution to the life of the UK and the world across a broad front. However, as physics is an enabling subject, impact underpinned by physics research can take a considerable time to reach maturity, particularly in terms of industrial products. Because of this, the sub-panel is strongly of the view that for any future REF exercise, the eligibility period for underpinning research in physics should be extended significantly.

9. A total of 203 case studies were submitted. While a case study often described more than one type of impact, the sub-panel classified the main area of impact of each under four broad headings: approximately 70 per cent were Economic; 5 per cent Environment and Health; 5 per cent Policy; and 20 per cent Public Engagement.

10. In assessing impact, the sub-panel observed the following:

a. There was compelling evidence for the impact of physics on the economy and industry. Although this impact was evident across the whole breadth of the subject, condensed matter physics, being closest to the electronics and similar industries, underpinned a significant proportion of the economic impact reported. Several topics noted in the Outputs section above, in particular photonics (sensors and light sources in environmental and healthcare applications), next-generation photovoltaics, polymer physics, graphene etc., have contributed greatly to this strong performance in industrial impact.

b. Physics outreach demonstrates not only massive impact via world-class TV and radio programming produced by practicing physicists but also ‘grass roots’ impacts, reaching out to communities not generally interested in science as well as to schools, science clubs etc. Full and inventive exploitation of web resources by physicists is key to the reach of this activity - e.g. blogs, social media, YouTube videos, crowd experiments, iPhone apps, games, etc. Physics tackles the ‘big questions’ – the origin, development and fate of the universe, the fundamental laws of nature, the most basic constituents of the universe, the mysteries of the quantum etc. – which excite the imagination of the general public. There seems little doubt that the sustained increase in numbers of children studying physics is directly related to this outstanding outreach activity, which was strongly represented in the REF submissions.

c. Impact case studies in the area of policy were often more difficult for submitting institutions to evidence. More detailed advice in this area would be helpful for future REF exercises.

d. The impact template submissions were sometimes not particularly well written and despite clear guidance, several consisted of little more than a list of impact case studies. If well written, the templates gave valuable information on the generic approach to impact. In future, more examples of good practice should be provided. As noted in the Main Panel report, the impact template in any future exercise should be combined with the environment template.

Environment

11. The research environment on average seems to be very healthy and if anything to have improved somewhat since RAE2008, although as rather different elements were measured in the two exercises, direct comparison is difficult.

12. In assessing environment, the sub-panel observed the following:

a. There was increasing evidence for pooling of resources in regional groupings, as pioneered during the period of RAE2008 by the Scottish Universities Physics Alliance (SUPA). SUPA has gone from strength to strength and resulted for the first time in a joint submission in Physics (Edinburgh and St Andrews) to an RAE or REF exercise. Other alliances that have been established since the RAE2008 assessment period are the Midlands Physics Alliance (founded in 2007 and expanded in 2010) and the South-East Physics Network (launched in 2008 and expanded following further funding in 2013). All have attracted new funding into the subject and are reported to have had a positive effect on the participants.

b. Some progress has been made in promoting workplace equality during the period, although there is still work to be done. As an indicator, there has been a significant uptake of the Institute of Physics Juno initiative, with almost 20 per cent of submitted units reporting that they have attained ‘Champion’ status (and a further 40 per cent either ‘Practitioner’ or ‘Supporter’). Around 20 per cent of submitting units reported that they had achieved Athena SWAN Silver status, but there were no Gold awards in physics during the assessment period. More than a third of submitting units did not report having achieved the European Commission HR Excellence in Research badge, and very few reported participation in the Stonewall Diversity Champions Programme. Three quarters of the submitting units expressed an intention to attain or upgrade their Juno or Athena SWAN status, and for the future health of the discipline, we urge them to do so.

c. In total, 302 early career researchers (ECRs) were identified in submissions, 17 per cent of the total headcount. This is a welcome indication that the strong recruitment of ECRs noted at RAE2008 has been maintained.

d. There is concern that several institutions that continue to produce world-leading outputs are doing so from environments that may not be able to sustain this in future.

e. The number of astronomers in the UK has increased significantly since RAE2008; funding has not kept pace and there is concern about the sustainability of current UK leadership.

f. At a unit of assessment level, total research income in the assessment period, excluding Research Council in-kind income, was just over £1.3 billion and showed an overall decrease in real terms of 3.6 per cent from the first year of the assessment period (2008-9) to the last (2012-13), using the Treasury gross domestic product deflator to adjust for the effects of inflation. Notably, for the Research Councils, who provided 77 per cent of the total funding in the assessment period, the total reduction in annual funding over the same period was 12 per cent, a point of serious concern for the sub-panel. In contrast, although a smaller funder overall, contributing only just over 10 per cent of all funding in the period, the growth in EU government funding in the period was 61 per cent.

g. On a more positive note, many individual submitting units were able to present evidence that their income from industry, EU and other non-RCUK sources had grown during the period, reflecting improved relationships with stakeholders (evident in the environment and impact templates) and a commitment to generating impact. However for most units, these sources still contribute a small percentage of the overall income and cannot compensate for a real-terms reduction in Research Council funding.

h. A very large resource is devoted to the provision of access for UK physicists to both national and international facilities, such as CERN, the European Space Agency, the European Southern Observatory, to name only the largest. This resource, and indeed the cost of access to additional facilities not provided by UK Research Councils, was taken into account in assessing environment, but is not included in the overall funding figures above. The estimated value of access provided by the Research Councils totalled £1.2 billion in the assessment period, with this support showing a reduction in real terms from the first to final year of the period of just under 11 per cent. Several anomalies were discovered in the information provided by the Research Councils in the attribution of this support to institutions. In any future exercises, the sub-panel recommends that close liaison between HEFCE and the Research Councils to ensure correct attribution of these resources is essential. Since the overwhelming majority of this resource is provided to physics, it would be desirable for the chair of a future physics sub-panel to be directly involved in this specification.

13. The overall picture of research in physics is of a very strong and agile research base, well able to respond to new intellectual and technological challenges. There are significant concerns, however, about funding across the board which, far from increasing, is being eroded in real terms in the UK, unlike many of our competitor nations, including large nations becoming increasingly active in the field such as China, India and Brazil. There must be concern therefore that the very strong performance evident in REF will not be sustainable without a marked improvement in the funding situation.

UOA 10: Mathematical Sciences

Summary of submissions and results

Submissions

	2014	2008	% difference
Number of submissions	53[1]	115[2]	-53.9%
Category A staff FTE	1,931	1,923	+0.4%
Category A and C staff headcount	2,005	2,029	-1.2%
Number of outputs	6,995	7,707	-9.2%
Outputs per Category A and C staff headcount	3.49		
Impact case studies	236	-	

Results

	Average percentage (Category A FTE weighted) judged to meet the standard for:				
	4*	**3***	**2***	**1***	**UC**
Overall	29	55	15	1	0
Output	22.7	59.7	16.8	0.6	0.2
Impact	35.9	46.6	14.1	2.3	1.1
Environment	44.2	47.4	8.1	0.3	0

1. Unit of Assessment 10, which covers all the mathematical sciences (but not computer science), is an amalgamation of three distinct units of assessment from RAE2008, namely Pure Mathematics, Applied Mathematics, and Statistics and Operational Research. This amalgamation worked well. Although 53 institutions submitted material in REF2014 UOA 10, compared with 56 which submitted in at least one of the Mathematical Sciences units of assessment in RAE2008, an almost equal volume of Category A staff were returned to both (1,931 FTE to REF2014 and 1,923 FTE to RAE2008). However, as a consequence of precise rules about the treatment of ECRs and other clearly defined staff circumstances, 6,995 outputs were submitted in UOA 10 whereas 7,707 had been submitted in the corresponding units of assessment in RAE2008. It is difficult to compare submission data from the three RAE2008 units of assessment with REF2014 data, largely because

[1] Two of these were the parts of a joint submission; there was only one joint submission.
[2] For the RAE HEIs were able to make submissions to separate sub-panels in pure mathematics, applied mathematics and statistics and operational research. A total of 115 submissions were to these sub-panels, but these submissions represented only 56 unique HEIs (21 HEIs submitted to only one sub-panel).

there is no information about institutions' submission strategies. It was noted that six institutions which submitted in one of the RAE2008 mathematical sciences units of assessment did not submit in UOA 10 in REF2014; all had submitted to only one RAE2008 unit of assessment, and five of the six were post-'92 universities. There was one new submission to REF2014.

2. There was evidence in the impact and environment templates of an increased level across all institutions of interdisciplinary and knowledge transfer activity (e.g. medical, industrial and public engagement). Concerning outputs, submissions tended to be in the core mathematical sciences although a reasonable number were interdisciplinary.

Outputs

3. To facilitate the allocation of outputs to panellists and the interpretation of the sub-panel's assessment at sub-discipline level, it would have been useful if outputs (or staff) had been identified with research groups. However REF2014 guidance left the use of research groups optional and the number of research groups reported in individual submissions to this sub-panel varied from zero to 27. This made it difficult to comment accurately and meaningfully on outputs in the preparation of confidential feedback statements for institutions.

4. Only three cases for double-weighting of outputs were received, of which two were judged to meet the criteria.

5. As set out in the panel criteria and working methods the sub-panel did not request additional factual information about the significance of outputs (100 word statements in addition to what would be evident from the outputs themselves), nor did it use citation information. The sub-panel was content that it was fully able to perform its assessment of outputs without these additional inputs. However a considerable number of outputs were cross-referred.

6. The largest number of outputs cross-referred from Sub-panel 10 to other sub-panels within Main Panel B (MPB) was 158 to Physics (Sub-panel 9) and 17 to Earth Systems and Environmental Science (Sub-panel 7). In addition, 13 outputs covering the history of mathematics were cross-referred to Philosophy (Sub-panel 32, Main Panel D) and one was referred to Economics and Econometrics (Sub-panel 18, Main Panel C). The advice received from all sub-panels which were consulted was extremely helpful in arriving at well-informed assessment decisions.

7. Sub-panel 10 received cross-referrals from other sub-panels. The largest numbers from outside MPB were 50 from Business and Management Studies (Sub-panel 19, Main Panel C) and 30 from Economics and Econometrics. From within MPB there were 25 cross-referrals from Physics (Sub-panel 9), with a smaller number from General Engineering (Sub-panel 15), Earth Systems and Environmental Science (Sub-panel 7), Chemistry (Sub-panel 8) and Electrical and Electronic Engineering (Sub-panel 13). In addition a small number of outputs were cross-referred from Agriculture, Veterinary and Food Science, Allied Health (Sub-panel 6), and Biological Sciences (Sub-panel 5), both in Main Panel A, and from Law (Sub-panel 20) and Sociology (Sub-panel 23), both Main Panel C.

8. In assessing outputs, the sub-panel observed the following.

   a. The overall quality of research outputs was high, with several quite exceptional and broadly based submissions of the highest international standards. All but one submission had a proportion of outputs judged to be world leading,

b. The number of internationally co-authored outputs was an impressive reflection of the vitality of the discipline.

c. Since RAE2008 there had been a notable increase in the quality and quantity of intradisciplinary research that cuts across field boundaries in the mathematical sciences.

d. World-leading research in pure mathematics (algebra, analysis, discrete mathematics, ergodic theory and dynamical systems, geometry, logic, number theory and topology) was spread widely across the submissions.

e. Since RAE2008 there had been an increase in quantity and quality of research in theoretical partial differential equations and in stochastic analysis (some of which was world-leading at the highest level).

f. A significant proportion of computational mathematics, including numerical analysis, image and signal processing, inverse problems, meteorology and areas of pure mathematics such as computational number theory, was judged to be high quality and found widely distributed throughout the submissions.

g. Continuum mechanics was widely represented in the submission, reflecting continued high quality UK research in fluid mechanics, magnetohydrodynamics and mathematical biology, as well as growing strengths in solid mechanics.

h. The growth of mathematical research in materials science and at the interfaces with analysis and probability reflects improvements in areas that were deemed lacking in the Engineering and Physical Sciences Research Council (EPSRC)'s International Review of Mathematical Sciences, December 2010.

i. The large submission in mathematical/theoretical physics showed breadth and depth in areas where the UK has been strong for decades. For example there were many world-leading outputs in quantum field theory (including string theory, integrable systems, high energy particle physics and cosmology), and aspects of general relativity and statistical mechanics.

j. In comparison with RAE2008 there had been a notable increase in activity on complexity, often of a very interdisciplinary nature; some of this work was of high quality.

k. The quality of interdisciplinary work, including mathematics in the life, medical and social sciences, was high but sometimes assessment posed challenges in terms of mathematical content versus scientific relevance, which led to cross-referrals.

l. The sub-panel particularly appreciated outputs that described innovative methodology that had been developed for and applied to specific practical problems, often as part of substantial cross-disciplinary research efforts.

m. Industrial mathematics is an area in which the UK is world leading. There had been significant growth since RAE2008 in the number of centres of excellence and the range of sectors with which they engage. This was reflected in both the number and quality of the impact case studies and templates submitted.

n. A substantial proportion of the outputs in statistics, probability and operational research was world-leading and helped to shape the international research agenda. Strength in core statistical methodology was broad, notably in computationally intensive methods and the analysis of high-dimensional data. There was evidence of growth of world-leading research in theoretical probability, and from operational research the sub-panel recognised large amounts of excellent work in optimisation.

Impact

9. There were 236 case studies of which 10 were described as 'not for publication', either due to their confidential nature or because they required security clearance. The sub-panel recognised that in the mathematical sciences the time between research being conducted and impact being created can be very long, pathways may not be linear, and auditing the pathway to impact may be challenging. In spite of this, the sub-panel was impressed by the quality, originality, and reach and significance of the submitted impact case studies, which covered a wide range of activities, including climate and environment, commercial and open source software, data analysis, engineering, epidemiology, finance, healthcare provision, industrial design and development, marketing, medical research, public engagement, public policy, risk management and security.

10. In assessing impact, the sub-panel observed the following.

a. The overall quality of impact case studies and templates was high and the international scope of many demonstrated the global value of UK mathematical sciences research.

b. About 50 per cent of case studies could be characterised as having been underpinned, mainly though not exclusively, by research in statistics and operational research, 45 per cent by applied mathematics, and 5 per cent by pure mathematics. However, many different aspects of the mathematical sciences were seen to contribute to a given impact case study.

c. More than half the case studies reported economic and industrial impact.

d. Impacts with reach of billions of pounds, numerous policies informed by evidence, multiple lives and assets (e.g. aircraft and ships) saved and hundreds of thousands of members of the public engaged in mathematics were clearly evidenced.

e. The confidential case studies were mainly of a very high standard in terms of their reach and significance and demonstrated some unexpected applications of mathematics to important problems in the areas of national security and public policy. Three quarters of these were based on pure mathematics.

f. In the best case studies the link between the impact claimed and the underpinning research, and the case that the underpinning research was undertaken within the submitting institution in the correct time frames, was articulated clearly, and the reach and significance of the impact was supported by explicit evidence.

g. In a number of case studies the underpinning research undertaken by the submitting unit was part of a large research effort by many institutions worldwide generating very substantial impact. In these cases it was helpful when the distinct and material contribution that the unit's contribution had made to which part of the overall impact was described. Good case studies made this clear.

h. There were high quality public-engagement case studies which showed breadth and originality.

i. Many case studies involved the development of modern mathematical, statistical and operational research methods, which were subsequently transportable to other problems, for the delivery of impact with high reach and significance.

j. Templates were generally well written and a small number of units had clearly demonstrated strong well-developed and wide-ranging strategies for engagement with users of the mathematical sciences.

k. While many templates promise excellent mathematical science impact at the next assessment, a small number suggested that impact strategies were not presently well developed.

l. Some templates indicated a strong focus on impactful research while others had different priorities, perhaps because of the balance of their current research portfolios.

Environment

11. Evidence of effective research leadership and elements of environment conducive to world-leading research were judged to be widely distributed and not restricted to large units. A strong indication of the vitality of UK involvement with the mathematical sciences worldwide was reflected in the large number of

a. submitted international collaborations, a significant fraction of which was judged world-leading;

b. fellowships and research grants, including European Research Council awards, won in open competition;

c. prizes, awards and distinguished lecture invitations.

12. Concerning strategy it was noted that in the mathematical sciences there had been some very effective

a. leadership in the cultivation of world-class research;

b. targeting of existing and new research areas for growth;

c. reorganisations of units into research groups;

d. recruitment of staff at all levels;

e. efforts to nurture talent through postgraduate and postdoctoral training;

f. plans for staff development and retention;

g. infrastructural development, including buildings, targeted at growth.

13. As evidence of good overall strategy it was noted that some larger units had cultivated multiple sources of funding to sustain significant activity in a wide range of research areas, while some smaller units had, with strong institutional support, planned notable success in more focused research.

14. There was a high percentage of ECRs in the overall submission (418 ECRs, which is 21 per cent of the total Category A and C headcount and slightly down from just under 22 per cent in RAE2008), and healthy recruitment into the UK of mathematical scientists from all over the world. However, there was clear evidence of the continuing concentration of staff, funding and activity into fewer larger departments. For example, although overall staff numbers across all submissions had

remained static, the four largest units submitted 497 FTE staff to REF2014, which is over 25 per cent of the total returned in UOA 10, a 12 per cent increase on figures from RAE2008. The sub-panel also noted that representation of statistics had declined in some submissions since RAE2008.

15. Total research income in the assessment period was just under £354 million which showed an overall increase in real terms of 22 per cent from the first year of the assessment period (2008-9) to the last (2012-13), using the Treasury gross domestic product deflator to adjust for the effects of inflation. This reflects well on the overall management of the mathematical sciences during a period when resources were limited. The Research Councils remain an important funder for the mathematical sciences community with 66 per cent of all funding in the assessment period from this source. While Research Council funding remained virtually flat across the assessment period, significant growth was seen in government funding, both UK and EU, which comprised around 15 per cent of all funding in the period. Growth in EU government funding between 2008-9 and 2012-13 was particularly high at just over 200 per cent. Industry funding also showed strong growth, increasing by just over 50 per cent between 2008-9 and 2012-13, and comprised just under 5 per cent of all funding in the period. All this shows a welcome diversification of research funding sources during the assessment period.

16. According to the standard analyses data for mathematical sciences, 2,515 doctoral degrees were awarded by submitting units during the assessment period, with a cumulative growth of approximately 50 per cent between the first and final years of the assessment period.

17. There was widespread commitment to equality and diversity. The sub-panel noted that 61 per cent of institutions had an Athena SWAN Bronze award, either at institution or unit level; 52 per cent had the HR Excellence in Research award; 38 per cent supported the London Mathematical Society (LMS)'s Good Practice Scheme and other LMS initiatives related to gender equality; 25 per cent referred to other initiatives supporting women staff, e.g. women's networks, mentoring, etc.;15 per cent made reference to initiatives relating to disability, e.g. Two Ticks scheme, access issue, and 12 per cent made reference to LGBT initiatives, e.g. engagement with Stonewall.

18. In assessing environment, the sub-panel observed the following.

a. All submissions had been judged to have had a research environment that was at least 70 per cent internationally recognised in terms of vitality and sustainability.

b. Three large submissions had been judged to have had 100 per cent world-leading environments and seven more to have had environments that were 100 per cent internationally excellent with more than 50 per cent world-leading.

c. The sub-panel judged that some environment templates appeared to have been generated by institutions centrally with relatively limited regard for the discipline specifics of particular submissions. This was unhelpful to the assessment of the environment of the unit itself.

UOA 11: Computer Science and Informatics

Summary of submissions

Submission data for Sub-panel 11			
	2014	**2008**	**% difference**
Number of submissions	89	81	+9.9%
Category A staff FTE	2,045	1,839	+11.2%
Category A and C staff headcount	2,159	1,910	+13.0%
Number of outputs	7,668	7,491	+2.4%
Outputs per Category A and C staff headcount	3.55		
Impact case studies	280	-	

1. Sub-panel (SP) 11 covers the broad subject area of computer science and informatics. We received 89 submissions with a total of 7668 outputs, making this one of the larger areas of research returned to REF2014. Submissions covered a wide range of interdisciplinary areas, from computer hardware engineering through to computer-generated works of art, with work in biology, medicine, psychology, the humanities, and education as well as the more obvious overlaps with electrical engineering, physics and mathematics.

2. In core computer science areas there are considerable bodies of work in artificial intelligence, computer vision and in algorithmics and theoretical areas. The most substantial inter-disciplinary area is the overlap with life and medical sciences.

3. Overall, the Sub-panel 11 outcomes show that Computer Science and informatics is in good health across the UK. The following table summarises the overall assessed quality profile and the individual sub-profiles for outputs, impact and environment.

Category A FTE Volume weighted profiles for Sub-panel 11					
Profile Type	**% 4***	**% 3***	**% 2***	**% 1***	**% UN**
Overall	**26**	**44**	**24**	**5**	**1**
Output	22.1	47.1	25.8	4.8	0.2
Impact	36.9	38.0	15.0	7.8	2.3
Environment	27.4	42.5	23.5	6.5	0.1

Outputs

4. SP 11 observed that the capability analysis undertaken by the EPSRC accurately represents the strength and shape of UK Computer Science and Informatics. The discipline was well aligned with both the Industrial Strategy and the 'Great Technologies'.

5. SP 11 observed a distinct trend towards publication in established venues that are often associated with high refereeing standards. This is encouraging as researchers are testing the rigour of their work against high international standards. We also noted that the reputation of a journal is becoming even less of an indicator of quality than hitherto.

6. Outputs returned to SP 11 reflected the enormous diversity of the subject domain, with broadly theoretical areas remaining a particular strength of UK academic computing research. The emerging areas in the discipline that are creating widespread excitement are in the networking systems area, such as the 'Internet of Things', developments in intelligent systems such as driverless cars, computer vision and robotics, and in 'big data' and data analytics. There are strong signs of a trajectory in theoretical computer science towards real applications, a movement from discrete towards continuous maths, and interest in ultra-scale systems. There is much evidence of contributions to the underpinning innovation base in the UK, e.g. health and life sciences, and human-centred computing. Areas likely to feature more strongly in the future include cyber-security and information and communication technology (ICT) ethics.

7. SP 11 accepted a very wide range of interdisciplinary outputs falling within its remit, provided that there was some contribution to computer science and informatics. Such outputs were assessed on their broad contribution, not simply on their computer science and informatics content. The only papers cross-referred to other sub-panels were those in which the major content fell in the scope of Art and Design (cross-referred to SP 34) or in the Performing Arts (cross-referred to SP 35). In all other cases the sub-panel determined it was competent to assess the inter-disciplinary content within the framework of the REF guidelines.

8. SP 11 received incoming cross-referral requests from many sub-panels, the great majority of which were accepted and handled by SP 11 members on the same basis as outputs submitted directly to the sub-panel. The few such cross-referral requests not accepted by SP 11 were declined on the grounds they fell outside the sub-panel's sphere of competence.

9. The largest single topic area in the UOA was artificial intelligence, with over 1,000 outputs representing over 13 per cent of all outputs returned, showing that UK research in intelligent systems is vibrant. There were also significant numbers of outputs in Machine Learning (402), Computer Vision (431), Models of Computation (455), Human-Centred Computing/Visualisation (568) and Algorithms and Theory (416). The quality profile did not vary much with topic area, though the theoretical work had perhaps the strongest overall profile across the UOA. The table below gives the detailed analysis of submitted outputs by topic. Many outputs reflected the interdisciplinarity of the subject, with computing applications in life sciences, medicine, psychology, geoscience and physics. (These data should be treated with circumspection as they represent a single snapshot of outputs selected just for REF2014 and were gathered primarily to help in the allocation of outputs, where they were very useful.)

SP 11 Computer Science and Informatics: Topic Analysis of Outputs

Topics	Topic no.	Total outputs	% of outputs	* rating					% rating of overall submission by topics				% rating within topics			
				4	3	2	1	U	4	3	2	1	4	3	2	1
Hardware	1	235	3.1	38	135	54	8		0.5	1.8	0.7	0.1	16.2	57.4	23.0	3.4
Computer systems organisation	2	201	2.6	45	106	39	11		0.6	1.4	0.5	0.1	22.4	52.7	19.4	5.5
Real-time and fault-tolerant systems	3	22	0.3	9	7	5	1		0.1	0.1	0.1	0.0	40.9	31.8	22.7	4.5
Networks (protocols)	4	121	1.6	17	64	33	7		0.2	0.8	0.4	0.1	14.0	52.9	27.3	5.8
Networks (algorithms)	5	104	1.4	15	41	37	11		0.2	0.5	0.5	0.1	14.4	39.4	35.6	10.6
Networks (properties and services)	6	218	2.8	37	87	76	18		0.5	1.1	1.0	0.2	17.0	39.9	34.9	8.3
Software organisation and properties	7	340	4.4	71	177	65	27		0.9	2.3	0.8	0.4	20.9	52.1	19.1	7.9
Software notations and tools/ parallel programming languages	8	178	2.3	45	87	43	3		0.6	1.1	0.6	0.0	25.3	48.9	24.2	1.7
Software creation and management	9	192	2.5	35	96	51	10		0.5	1.3	0.7	0.1	18.2	50.0	26.6	5.2
Models of computation/ formal languages/ complexity/ semantics	10	455	5.9	124	234	94	3		1.6	3.1	1.2	0.0	27.3	51.4	20.7	0.7
Logic	11	305	4.0	102	154	49	0		1.3	2.0	0.6	0.0	33.4	50.5	16.1	0.0

Topics	Topic no.	Total outputs	% of outputs	* rating					% rating of overall submission by topics				% rating within topics			
				4	3	2	1	U	4	3	2	1	4	3	2	1
Design and analysis of algorithms/ randomness/ theory/ methodologies	12	416	5.4	134	202	68	12		1.7	2.6	0.9	0.2	32.2	48.6	16.3	2.9
Mathematics of computing	13	296	3.9	59	142	83	12		0.8	1.9	1.1	0.2	19.9	48.0	28.0	4.1
Information systems	15	220	2.9	43	90	69	18		0.6	1.2	0.9	0.2	19.5	40.9	31.4	8.2
World wide web	16	125	1.6	22	45	46	12		0.3	0.6	0.6	0.2	17.6	36.0	36.8	9.6
Information retrieval/ document management and text processing	17	153	2.0	27	66	51	9		0.4	0.9	0.7	0.1	17.6	43.1	33.3	5.9
Cryptography	18	55	0.7	25	21	6	3		0.3	0.3	0.1	0.0	45.5	38.2	10.9	5.5
Security services/ hardware/ systems	19	207	2.7	54	83	61	9		0.7	1.1	0.8	0.1	26.1	40.1	29.5	4.3
Human-centred computing/ visualisation	20	568	7.4	57	278	195	38		0.7	3.6	2.5	0.5	10.0	48.9	34.3	6.7
Collaborative and social computing	21	160	2.1	14	75	58	13		0.2	1.0	0.8	0.2	8.8	46.9	36.3	8.1
Artificial intelligence	22	1011	13.2	256	490	225	40		3.3	6.4	2.9	0.5	25.3	48.5	22.3	4.0
Computer vision	23	431	5.6	143	195	83	10		1.9	2.5	1.1	0.1	33.2	45.2	19.3	2.3
Machine learning	24	402	5.2	88	199	104	11		1.1	2.6	1.4	0.1	21.9	49.5	25.9	2.7
Modelling and simulation	25	94	1.2	13	47	31	3		0.2	0.6	0.4	0.10.0	13.8	50.0	33.0	3.2
Computer graphics	26	205	2.7	57	90	53	5		0.7	1.2	0.7	0.10.1	27.8	43.9	25.9	2.4

Topics	Topic no.	Total outputs	% of outputs	* rating				
				4	3	2	1	U
Applied computing	27	140	1.8	20	53	63	4	
(Applied computing) life and medical sciences	28	517	6.7	133	253	109	22	
(Applied computing) law, social, arts, humanities, education, other domains	29	176	2.3	9	67	76	24	
Other topics, includes operations research, history, education and others	30-33	102	1.3	6	32	45	19	
Total		**7668**		**1698**	**3616**	**1972**	**363**	**19**

% rating of overall submission by topics			
4	**3**	**2**	**1**
0.3	0.7	0.8	0.30.1
1.7	3.3	1.4	0.30.3
0.1	0.9	1.0	0.00.3
0.0	0.1	0.1	0.0
22.1	**47.2**	**25.7**	**4.7**

% rating within topics			
4	**3**	**2**	**1**
14.3	37.9	45.0	2.9
25.7	48.9	21.1	4.3
5.1	38.1	43.2	13.6
5.9	31.4	44.1	18.6

Impact

10. A lot of research in the SP 11 area has direct, global impact, and this was reflected in the impact case studies submitted to the UOA. Taken together these case studies demonstrate very impressive and substantial impact from computer science and informatics research, which is perhaps unsurprising as computer systems now underpin pretty much all human activity, from research in other sciences, through business, education, entertainment, and into the heart of government. This diversity is reflected in the wide range of impact types submitted. These included: influencing policy and standards; economic impact through start-up companies and collaborations with industry; contributions to commercial and public domain software infrastructure; work with the health services, and public engagement activities. All impact types were welcome and were assessed on an equal footing.

11. SP 11 noted the high quality of many of the impact cases submitted and the outstanding contribution to what might be broadly termed the digital economy. Many institutions are deriving high value intellectual property from their research and have been successful in translating it into practice. The engagement of university technology transfer offices in facilitating this was noted in many cases. Contributions to standards were amongst the highly rated impact cases as were the development of significant software infrastructures. Some case studies, where the benefits and achievements were clear, had difficulty in providing direct traceability to underpinning research. This problem is, we judge, a particular issue in software innovation and may lead to the overall research impact of computer science and informatics being underestimated in the REF.

Research environment

12. Computer Science and Informatics is in rude health, though there is some evidence that flat-line funding is having an effect at the margins. Overall funding has been stable, with a drop of 1.9 per cent in real terms over the REF period. This masks a significant drop in research council funding of 12.5 per cent in real terms over the REF period that has been largely offset by the growth in EU funding of 18.8 per cent in real terms over the same period. An impressive cadre of ECRs has been developed and the number of doctoral degrees awarded in Computer Science and Informatics has grown by just under 30 per cent over the REF period, and it will be important to ensure the research funding is present to sustain the future growth that this implies. The cessation of capital funding through the Science Research Investment Fund has meant that we have seen fewer capital developments than in 2008. This may be a matter of concern as the responsibility falls to the institutions to support the growth of the discipline.

13. Computer Science and Informatics faces particular challenges in ensuring the representation of women. Virtually all submissions recognised this and had actions in place to address the problem. Many had applied for, or achieved, Athena SWAN awards. Similarly many were engaged with national initiatives. Support for women doctoral students was commended with a number of institutions putting in place support mechanisms.

14. The most research active institutions returned to SP 11 have vibrant and effective research environments with world-class facilities, world-class staff from diverse international origins, excellent career support systems in place for ECRs and other staff, and a significant output of PhD students, again with diverse international origins. Collaborative research and larger grants are a growing trend as the various funding bodies increasingly look for critical mass in the projects they resource. Significant EU funding into ICT gives a strong international flavour to much of the collaborative research. Collaborations often include industry as well as academic partners. Many institutions actively encourage multi-disciplinary research, and departments often lead or are involved in multi-disciplinary institutes and centres. SP 11 noted the particular contribution that

Computer Science and Informatics makes in support of the excellence of research in other disciplines across the spectrum.

UOA 12: Aeronautical, Mechanical, Chemical and Manufacturing Engineering

Summary of submissions

1. Sub-panel 12 – Aeronautical, Mechanical, Chemical and Manufacturing Engineering represents an amalgamation of RAE2008 Sub-panels G26 – Chemical Engineering and G28 – Mechanical, Aeronautical and Manufacturing Engineering. The table below gives a summary of the submissions received in REF2014, with comparative data for RAE2008 where this is available.

	2014	**2008***	**% difference**
Number of submissions	25	43	-41.9%
Category A staff FTE	1,153	1,274	-9.5%
Category A and C staff headcount	1,193	1,348	-11.5%
Number of outputs	4,154	5,222	-20.5%
Outputs per Category A and C staff headcount	3.48		
Impact case studies	138		

**2008 data is for sub-panels G26 and G28 combined*

2. The number of submissions to REF2014 has dropped by about two fifths from the equivalent submissions to RAE2008, with the majority moving to Sub-panel 15 – General Engineering. Of the 25 submissions to Sub-panel 12: four were predominately chemical engineering; 13 were predominately aeronautical, mechanical or manufacturing engineering; and eight were integrated submissions of chemical and at least one of aeronautical, mechanical and manufacturing engineering. Three institutions provided two submissions, separately representing chemical engineering and aeronautical, mechanical or manufacturing engineering. Where submissions were integrated, such integration appeared genuine and where there were separate submissions, this approach also appeared to be justified.

3. The table below gives the overall volume weighted (by Category A FTE) profile and the volume weighted output, impact and environment sub-profiles for Sub-panel 12.

Profile Type	**% 4***	**% 3***	**% 2***	**% 1***	**% U**
Overall	**25**	**57**	**17**	**1**	**0**
Output	18.0	60.4	20.7	0.8	0.1
Impact	38.4	47.0	13.9	0.7	0.0
Environment	36.8	55.0	6.4	1.6	0.2

4. The health of aeronautical, mechanical, chemical and manufacturing engineering, as represented by submissions to this sub-panel is good, with 82 per cent of the overall volume

weighted profile for the sub-panel and almost 80 per cent of the outputs assessed as internationally excellent or higher in terms of originality, significance and rigour. The impact is also very high, from product and service development through policy to public engagement activities. The research environment is very good in a number of the submissions, but in others it could be further improved. Over the period of the REF, research income has risen in real terms by over 20 per cent, with a particularly notable increase reported in EU funding. Doctoral degrees awarded over the same period have increased by 7.5 per cent.

Outputs

5. Sub-panel 12 saw submissions primarily from Aeronautical, Mechanical, Chemical and Manufacturing Engineering, representing an amalgamation of RAE2008 sub-panels G26 – Chemical Engineering and G28 – Mechanical, Aeronautical and Manufacturing Engineering. A significant number of the submissions to RAE2008 G28, both large and small, did not submit to REF2014 Sub-panel 12, choosing instead to submit to Sub-panel 15 – General Engineering. As a result, it is difficult to comment conclusively on the overall health of the discipline.

6. Analysis of the outputs submitted revealed the following breakdown: Aeronautical (15 per cent); Mechanical (30 per cent); Chemical (25 per cent); Manufacturing (15 per cent); Energy (10 per cent); and Other (5 per cent). Those categorised as ‘energy’ outputs were identified as such by the submitting institutions and often spanned more than one of the main categories. Those marked ‘other’, all from a single submission, did not fit any of the categories and were cross-referred to Sub-panel 7 for advice on scoring. In all areas, the profile of scores matched closely with that of the overall output scores for the sub-panel.

7. The sub-panel welcomed an increase in multi-disciplinary papers and was confident that it was able to assess these robustly within the REF process; it would welcome more such submissions in the future. Similarly, the sub-panel would welcome more policy related outputs. It also expected, and would have welcomed, more ‘non-paper based’ outputs – patents, government reports, etc. Despite assurances, HEIs still appear reluctant to submit outputs other than journal articles.

8. The sub-panel noted the emergence of a stronger science base underpinning the research, for example more chemistry was included in Chemical Engineering, and an increase in multi-disciplinary work within medical and biological submissions. They also noted good applications of modelling at the nano-scale within materials sciences. Whilst the sub-panel was pleased to see many good applications of existing techniques to interesting challenges, far too many were incremental in nature.

9. The additional factual information on significance, ‘the 100 words’, were of value to this sub-panel. However, a significant number of HEIs did not use them effectively, many simply summarising the paper rather than providing the additional information requested by the Main Panel B criteria.

10. The sub-panel noted that where groups had merged to form a single submission, the outputs from them demonstrated that the integration was real and that there were genuine interactions and connections between them. Equally, where HEIs made more than one submission to the sub-panel, this would seem to have been appropriate given the diversity of the outputs reviewed.

Impact

11. The sub-panel was impressed by the range of types of impact submitted for review, including policy, economic and public engagement activities, and pleased by the overall quality.

There was strength in depth. The sub-panel would have welcomed more products presented in case-studies and observed that cases of successful commercialisation were limited. It also noted that a number of the case-studies submitted had not yet reached their full potential with regard to impact.

12. The sub-panel was confident that it was able to judge impact across the full range of types submitted, but found this easier when there was clear evidence provided by the HEI. All case-studies were reviewed and discussed by multiple academic and user panel members and impact assessors, using the template to provide valuable context for the individual case-studies. The sub-panel 'user' members and impact assessors were fully engaged in this process, contributing half of the case-study reviews.

13. The sub-panel felt that the number of case-studies requested for each submission was appropriate, not only from the point of view of demonstrating a spread of impact, but also with regard to the reviewing effort required.

Research environment

14. For the same reasons given in the Outputs section, it is difficult to comment conclusively on the overall health of the discipline. However, there was much evidence presented of excellence in the research environment, suggesting good health and sustainability.

15. The sub-panel noted that in many strategy statements, there was a variety of quality; a lack of specifics on how objectives from RAE2008 had been met, and claims of ambition for the future but no evidence of how they are going to be achieved. There was also a lack of SMART action plans. The sub-panel also noted the tendency for individual centres, institutes, etc. within a given submission to have their local strategies rather artificially forced together within a single overall strategy.

16. The sub-panel noted that ECRs were much more likely to have better support than in the past; mechanisms for this have generally improved. They also observed that a number of HEIs offered a challenge-led agenda for new researchers.

17. The sub-panel raised some concern regarding the utility of the data on research degree awards and research income provided in the REF4a and REF4b forms, and found that comparison between submissions using the data provided in the standard analysis was difficult.

18. As with the Outputs, the sub-panel noted that where groups had merged to form a single submission, the descriptions of the research environment demonstrated that the integration was real and that there were genuine interactions and connections between them. Equally, where HEIs made more than one submission to the sub-panel, this would seem to have been appropriate given the differences described within the environment statements reviewed.

UOA 13: Electrical and Electronic Engineering, Metallurgy and Materials

Summary of submissions

UOA 13	Electrical and Electronic Engineering, Metallurgy and Materials		
	2014	**2008**	**% difference**
Number of submissions	37	54	-31.5%
Category A staff FTE	1,071	1,216	-11.9%
Category A and C staff headcount	1,113	1,292	-13.9%
Number of outputs	4,028	4,965	-18.9%
Outputs per Category A and C staff headcount	3.62		
Impact case studies	141	-	

	% 4*	**% 3***	**% 2***	**% 1***	**% u/c**
Overall	**25**	**62**	**11**	**2**	**0**
Outputs	19.7	67.7	11.3	1.1	0.2
Impact	36.5	49.0	12.1	1.6	0.8
Environment	30.7	53.7	13.9	1.7	0.0

1. The sub-panel's remit was a combination of those of RAE2008 sub panels 24 (Electrical and Electronic Engineering) and 29 (Metallurgy and Materials) and high quality submissions were received from both of these areas. Of the nine universities that submitted to both predecessor sub-panels in RAE2008, only one put in a single submission to REF2014 Sub-panel 13. Five universities requested separate submissions for their corresponding departments, and all such requests were approved.

2. Submissions which gave a breakdown into research groups provided scope for the sub-panel to give more specific feedback and also helped to put into context the contribution that each research group made to the overall submission.

Outputs

3. 87.4 per cent of the outputs submitted to this sub-panel were judged to be of world-leading (4*) or internationally excellent (3*) quality. In many cases the information provided in the 100 word additional information statements proved to be both helpful and constructive, although others were left blank or abstracted the output.

4. The sub-panel was pleased to note a high proportion of outputs which showed demonstrable significance in terms of their likely commercial or industrial application, leading to impacts for the benefit of the UK and beyond. Interdisciplinary outputs which clearly showed the original research contribution to electrical and electronic engineering, or metallurgy and materials, were welcomed by the sub-panel.

5. The sub-panel noted an increased number of papers focussing on functional materials rather than structural materials and fewer on mechanical properties, reflecting current industrial priorities. Strength was also observed in research into aerospace materials, particularly engine alloys, which linked directly to some of the impact case studies submitted to this sub-panel. There was also evidence of growth in the number of outputs in clean energy and healthcare, in line with the RCUK priority research areas, as well as in nanoscience and graphene-related research. The sub-panel also saw a growth in the number of outputs based solely on simulation, which had little, if any, form of validation that would have demonstrated the rigour of the research.

6. As stated in the published working methods, the sub-panel did not use citations in its deliberations and this was conducive to an objective assessment of the content of the outputs. The sub-panel would recommend that this remains the procedure for future exercises.

Impact

7. The sub-panel received many examples of outstanding impact and noted many impacts which would continue to develop in the future. The sub-panel was impressed by the wide range of types of impact which were received and the scope and significance of the examples of impact submitted. The sub-panel saw impressive contributions made to the aerospace, rail, marine, energy, healthcare and manufacturing industries, as well as in many other areas, in addition to excellent contributions to policy and to environmental protection and sustainability. It was notable that the companies and organisations involved included major nationally and internationally known, well-established brands employing many thousands of people, as well as less well known organisations, throughout complex supply chains. There were also a significant number of small start-up companies, formed as a direct consequence of the academic research, some of which had been nurtured and grown through investment by regional and national bodies, as well as by other sources of funding.

8. The research users, who included some members of the sub-panel as well as the specially-appointed impact assessor, brought invaluable expertise, insight, and experience to the assessment of impact. The sub-panel recommends that an even greater role be assigned to the users in the assessment of impact in future research assessment exercises.

Impact templates

9. The sub-panel was impressed by impact templates that provided evidence of systems and processes underpinned by exemplars. The best of these concentrated on the mechanisms for achieving impact and also gave consideration to the role of staff development and support. Templates that developed an effective strategy and plans in addition to describing the approach to impact were welcomed, although the sub-panel would also have welcomed more emphasis on metrics for measuring and quantifying impact. The emphasis in some institutions on the assistance provided to academic researchers to enable the exploitation of their research was notable. The variety and scope of the mechanisms used to achieve this were necessarily diverse. More information about unit-specific activities would have been appreciated, with less reliance on information about generic institutional structures.

Impact case studies

10. The impact case studies demonstrated the significant economic importance of the sub-panel’s disciplines. Case studies that were set in a historical context enabled progression to be readily understood, and the real contribution of the submitting unit to be recognised. The sub-panel was keen to see traceable and realistic claims. In many case studies more quantitative evidence of the impact in the assessment period would have been helpful, and in some cases the extent of the institution's contribution to the impact claimed was exaggerated. On the whole the sub-panel found case studies which focussed on one or two key impacts rather than diffuse, multiple small impacts, more convincing. Corroborative evidence needs to be specific and informative.

Environment

11. The evidence presented to the sub-panel demonstrated that the research environment in these disciplines is overwhelmingly internationally excellent or world-leading. Many institutions provided forward-looking, exciting, dynamic and effective strategies, showing a clear and coherent vision for their future research activities and building on the strategies they outlined in their RAE2008 submissions. There is clear evidence of investment in human capital including training, diversity, equality of opportunity and postgraduate development. There has also been significant investment in major capital intensive equipment and facilities in key centres and institutes, for example for more recent, complex discipline areas such as nanotech and graphene, but also where research was targeted on manufacturing at, or close to, industrial scale. It was noted that, in addition to the investment in major national centres, smaller institutions demonstrated that investment in niche areas was essential and contributed significantly to the establishment and maintenance of high quality research outputs. Associated with investment in infrastructure, experienced high level technical specialists in the operation and use of equipment were complementary members of research teams. The submissions show that these disciplines benefit from a strong ethos of collaborating nationally and internationally, both with academe and with industry. The submissions show a strong diversity of income sources, with close to 50 per cent of research income non-RCUK based, including industry, EU and other sources.

UOA 14: Civil and Construction Engineering

Summary of submissions and results

Submissions

	2014	2008	% difference
Number of submissions	14	23	-39.1%
Category A staff FTE	391	513	-23.8%
Category A and C staff headcount	418	544	-23.2%
Number of outputs	1,384	2,066	-33.0%
Outputs per Category A and C staff headcount	3.31		
Impact case studies	51	-	

Results

	Average percentage (Category A FTE weighted) judged to meet the standard for:				
	4*	**3***	**2***	**1***	**UC**
Overall	24	56	16	3	1
Output	18.1	58.0	19.3	4.3	0.3
Impact	33.9	52.5	11.4	0.0	2.2
Environment	35.1	56.5	7.9	0.5	0.0

1. The sub-panel received 14 submissions, comprising 391.45 FTE Category A staff. In comparison with RAE2008, several HEIs with civil engineering units submitted to Sub-panel 15, General Engineering in Main Panel B, and a small number to Sub-panel 16, Architecture, Built Environment and Planning in Main Panel C.

2. The sub-panel comprised 12 panel members, including two user members, and one impact assessor. Amongst the 10 academics on the sub-panel, one had recently moved from industry. All of the scoring was calibrated against that of the other engineering sub-panels (via MPB) and between individual panellists within the sub-panel.

3. Overall the submissions to the sub-panel covered the full spectrum of quality, with approximately one quarter of the material submitted being assessed as world-leading. There was a distinct overall improvement in the quality of research submitted compared with RAE2008.

4. The factual information about the significance of an output not evident within the output itself (100 word statements) and the impact case studies were particularly informative. All submissions had some elements of world-leading research in at least one specialist area/sub-discipline.

Outputs

5. In total 1,384 outputs were submitted across the full range of civil engineering disciplines, with the vast majority comprising journal publications. In addition some conference papers, books, reports and one software item were submitted. One output was cross-referred to another sub-panel; 59 were cross-referred to the sub-panel from other sub-panels, the majority of these being from Sub-panels 16 (Architecture, Built Environment and Planning) and 34 (Art and Design: History, Practice and Theory).

6. The outputs were assessed to be particularly strong in water, structural materials, transport, and geotechnical engineering research. In water research a high proportion of fluid mechanics outputs were assessed as being internationally excellent or world-leading. Advanced structural analysis remained a key theme, enhanced by the availability of increasing computing power. The transport outputs covered a diverse range of interdisciplinary topics and were judged to have (marginally) the highest proportion of world-leading outputs. Areas of particular strength and growth included: modelling of traffic and networks, economics and econometrics, behavioural response, Global Positioning Systems and intelligent transport. Geotechnics and earth sciences outputs remained strong, attracting (by a narrow margin) the highest average output scores.

7. With regard to areas of growth or decline and emerging areas of research, there were many more submissions addressing sustainability, infrastructure resilience, life-cycle analysis and climate change compared with RAE2008. However, there was a decline in non-destructive testing and structural health monitoring submissions, although these topics remain internationally important. Other strong areas of growth included marine renewable energy, and water, food and energy security research, with continued growth in flood risk assessment, ecosystems services, remote sensing, geomatics, informatics and ‘big data’. Research in mainstream geotechnics continued to be strong, with outputs showing a trend away from experimental and theoretical geomechanics and towards environmental geotechnics, geothermal analysis and geochemistry. In addition, the topics of geophysical, earthquake, offshore and climate change analysis, nuclear waste disposal and infrastructure resilience were all more prevalent than in RAE2008. There was an increase in submissions concerning water sanitation and health in developing countries.

8. In comparison with RAE2008 there were marked changes in the types of research which had been undertaken, including rapid development across all areas in advanced numerical methods, with parallel computing and informatics playing an increasingly major role. These changes were often supported by novel field and laboratory investigations, with evidence of new investment in laboratory and field-based research facilities, after a prolonged decline in the field.

9. The sub-panel noted an increase in interdisciplinary and multidisciplinary research, including:

   a. increasing and diverse research activity in flood risk management, climate change, renewable energy, biodegradation of pollutants, geochemistry, environmental assessment, sensor technology, acoustics and remote sensing;

   b. a marked increase in multidisciplinary applications of microbiology, electrochemistry and nanotechnology, complemented by closer associations with socio-economic and synthetic biology research; and

   c. a significant volume of multidisciplinary research addressing policy, social science, health, disability and economic topics.

Impact

10. While case studies often described more than one type of impact, of the 51 impact case studies submitted, approximately 30 per cent demonstrated principally economic impact, the same proportion primarily benefited engineering practitioners, around 25 per cent affected public policy and services, and about 15 per cent related to environment and health. Many of the impact case studies showed strong evidence of multidisciplinarity, involving industrial, societal and government agency engagement.

11. Impacts described in the case studies included software and commercialised products, involving both spin-outs and direct arrangements with companies from small and medium-sized enterprises to large multinational consulting and contracting firms. There was considerable evidence of technology transfer and high impact via early engagement with end-users, together with strong evidence of research impacting on national and international best engineering practice and public policy.

12. In terms of the quality of submissions, the sub-panel determined that there was a very high proportion (86 per cent) of impact case studies demonstrating very considerable to outstanding significance and reach, with many examples of major contributions to: society in the UK and internationally, the UK and international economies, the built and natural environment, and public engagement activities. The greater number of impact case studies were in the water and environment, transport and geomatics areas, with the highest quality case studies often being associated with groups with well-developed links with industry, government departments and/or public agencies.

13. The impact templates submitted showed a wide range of approaches and maturities towards enabling impact. Those performing well demonstrated an established overarching strategy and a broad range of highly developed approaches towards enabling impact. These templates also evidenced high levels of alignment with wider HEI initiatives and, for the very best, strong strategic engagement at regional, national and international levels. Submissions that performed less well tended to lack an overarching strategy, or the strategy only connected with, or was reliant upon, a reduced number of impact enabling mechanisms.

Research environment

14. The research environment templates exhibited strong evidence of sustainability and vitality of the unit of assessment overall. Over 60 per cent of the submitting units had environments that were judged to be conducive to producing research that was of internationally excellent or world-leading quality. Most submitting units had performed well against their plans as stated in the RAE2008 submissions. Furthermore, there was clear evidence of units building on their strengths in key areas, and where they had critical mass.

15. Total research income showed an overall increase in real terms of 5 per cent from the first year of the assessment period (2008-9) to the last (2012-13), using the Treasury gross domestic product deflator to adjust for the effects of inflation. Income sources varied; across the assessment period approximately 48 per cent were from Research Councils, 28 per cent from government bodies (UK and EU) and 17 per cent from industry, with the balance from charities and other sources. Most submissions also reported significant investment by their own universities and government sources in the physical research environment.

16. Active research staff recruitment was evident in most submissions. There was also clear evidence of strategic planning in senior appointments and the quality of outputs associated with such staff was generally very high. Most units recruited staff from a variety of backgrounds,

including: chemistry, geology, biochemistry, mathematics, materials and social science/economics, in addition to engineers. The outputs associated with many ECRs were of a high quality, with their contributions boding well for the future vitality of their institutions and subject areas.

17. The sub-panel was pleased to note the high level of engagement with Athena SWAN, both at institutional and unit level, with over three quarters of submissions citing awards at either bronze or silver level. There was a lower – but encouraging – level of engagement reported regarding other aspects of diversity. For example, one fifth of submitted units reported engagement with Stonewall as diversity champions. Many also referred positively to the often highly international nature of their staff and students.

18. The sub-panel was also pleased to note the high level of national and international research collaboration, with much of this collaborative work being multidisciplinary in nature and with a wide range of stakeholders. Collaboration with networks of UK science and engineering departments was reported, as well as multidisciplinary collaboration with teams undertaking research in materials, computing, medicine and socio-economic aspects, to mention but a few.

19. There was considerable evidence of international collaboration, particularly with Europe, the USA, Australia, Asia and Africa, as well as strong interaction with industry and government. Funding was cited for chairs, e.g. from Arup, CH2M Hill, the Geotechnical Consulting Group, Laing O'Rourke, etc. and a number of major research programmes were sponsored by international agencies, e.g. UNESCO (United Nations Educational, Scientific and Cultural Organisation), WHO (World Health Organisation), Bill and Melinda Gates Foundation, etc. It was also pleasing to note that increasing funding was provided by regional, UK and international governments (e.g. China and India), as well as large international corporations, such as KBR Inc., Halliburton, Shell, BP and EDF. Finally, there was also considerable evidence of engagement and collaboration in setting international standards and practice recommendations with the UK and EU governments, the International Organisation for Standardisation, international agencies (such as UNESCO) and other regulatory and advisory bodies.

UOA 15: General Engineering

Summary of submissions

UOA 15	General Engineering		
	2014	**2008**	**% difference**
Number of HEI submissions	62	52	+19.2%
Category A staff FTE	2,447	1,454	+68.3%
Category A and C staff headcount	2,555	1,569	+62.8%
Number of outputs	8,697	6,041	44.0%
Outputs per Category A and C staff headcount	3.40		
Impact case studies	291	-	

	% 4*	**% 3***	**% 2***	**% 1***	**% u/c**
Overall	**26**	**56**	**16**	**2**	**0**
Outputs	17.2	65.8	15.5	1.0	0.5
Impact	41.6	39.8	15.5	2.3	0.8
Environment	46.5	34.9	16.4	2.2	0

1. Unit of Assessment (UOA) 15 (General Engineering) received submissions from 62 HEIs comprising 2,447 full time equivalent (FTE) Category A staff and a total of 2,548 Category A individuals and 7 Category C individuals. The sub-panel noted that there had been an increase in the number of HEI submissions from 52 in General Engineering in RAE2008 to 62 in REF2014. The submissions were from departments and schools of widely varying size that ranged from entire large departments in long-established universities through thematically or discipline-selected submissions to much smaller submissions from newer universities and from specialised research units. There was considerable evidence of restructuring during the assessment period and many institutions were submitting to General Engineering for the first time. The range of research disciplines was very wide and there was extensive evidence of interdisciplinary and internationally-collaborative research. Significant industrial involvement was identified.

2. The overall quality of research was found, in general, to be very high with 83 per cent of outputs assessed in terms of originality, significance and rigour as being of at least internationally excellent quality. The impact of research was found to be high with over 81 per cent of the volume weighted impact results judged to have very considerable or outstanding reach and significance. Environment submissions were similarly found to be of a high standard with over 81 per cent of

the volume weighted environment results judged to demonstrate vitality and sustainability conducive to producing research of internationally excellent or world-leading quality.

3. The overall quality of the research outputs submitted affirmed the academic and scientific health of the themes within the General Engineering discipline. There was evidence of investment and growth across the institutions submitted but the landscape now features a number of larger institutions where the scale of the environment appears conducive to the production of relatively high impact. The increase in numbers of early career researchers and PhD students, the increasing activity across discipline boundaries and the investment in many institutions evidenced vitality and sustainability which was not restricted to the larger submissions, with some smaller submissions either newly entering or making significant improvement.

4. The sub-panel agreed that the administrative support and process mechanisms had been excellent and that the calibration and validation exercises had been very useful. There was remarkable coherence and consistency of grading.

Outputs

5. 62 submissions were received, comprising 8,697 outputs from 2,447 FTE Category A staff for assessment in REF2014, compared to 6,041 from 1,454 FTE Category A staff in RAE2008. The sub-panel noted that, in addition to the traditional general engineering areas, research being undertaken by SP 15 submissions covered a much wider and more diverse range of topics than in 2008. Outputs were within, but not limited to the following broad categories: bioengineering; chemical engineering; civil engineering; communications and signal processing; computational modelling; dynamics and control; electrical engineering; electronics; energy; environmental engineering; human factors; manufacturing; materials; mathematics; mechanics and structures; mining engineering; nuclear; optics and photonics; systems and sensors; thermofluids and transportation. The panel noted that many of the outputs were highly interdisciplinary and very internationally collaborative. Submissions made use of the ‘statements of additional information’ field in REF2 to emphasise the impact and significance of a particular output. The sub-panel found this information very useful in most cases. In some cases the brevity or institutional interpretation of intended purpose of the information in the field was less helpful.

6. After completing the assessment the sub-panel concluded that the overall quality of the research being undertaken was of a very high standard. There were some excellent examples of multidisciplinary research and strong evidence of industrial and international collaboration with, in many cases, significant impact. In every one of the above categories at least two thirds of the outputs were considered to be internationally excellent or world-leading. In areas of research such as communications and signal processing, thermofluids, optics and photonics and systems and sensors 20 per cent or more of the outputs were assessed to be world-leading. Some areas, such as optics and photonics, were high in terms of the percentage of world-reading research but small in volume returned. Some larger areas that each individually made up over 10 per cent of the overall total of outputs, such as bioengineering, energy and materials, evidenced research where close to 80 per cent was assessed to be internationally excellent or world-leading. All areas exhibited some world-leading output. The panel noted established and emerging pockets of excellence, often in quite small institutions. Some institutions were high in terms of the percentage of world-leading output but were very low in terms of staff numbers returned, encouraging caution in any comparisons of overall results. There was observed growth in the volume of bioengineering, energy and communications and signal processing research.

Impact

7. 62 submissions were received, comprising 291 impact case studies and 62 impact templates across a wide range of industry sectors including, but not limited to: aerospace and defence; automotive and transportation; bioengineering, pharmaceuticals and healthcare technologies; chemical and process engineering; construction and infrastructure; software and information technology and electronics and telecommunications. The user members' and impact assessors' experience mapped to these and other sectors.

8. Over 75 per cent of impact case studies were assessed to be reporting outstanding or very considerable impacts and over 60 per cent of impact templates to be reporting approaches conducive to achieving outstanding or very considerable impacts. Impacts in the aerospace and defence, automotive and transportation and bioengineering sectors above were each judged to be outstanding in over 40 per cent of their impact submissions.

9. The impact templates, taken as a whole, showed deep collaboration between UK universities and commercial/government and third sector organisations during the assessment period.

10. There was clear evidence of the application of fundamental research outputs leading to economic success for industry. Industrial impact included new products, often world-leading in their fields, and the establishment of successful spin-out companies. The sub-panel observed a number of world-class impacts in medical engineering where interdisciplinary teams of scientists, engineers and clinicians had developed exceptional capabilities.

11. International impact was clear in a small number of cases, for example through export of products or sale of spin out companies to offshore companies. However, international impact was not articulated in the majority of the impact templates.

12. After completing the assessment, the sub-panel reflected that institutions were not always clear about what impact was or whether it happened in the assessment period, and that the link between research and impact could in a small number of cases be tenuous. In some impact templates there was a clear overall strategy for achieving impact. Despite the broad range of disciplines in General Engineering, there was a high level of consistency in the individual views of the assessors and full agreement of the final scores.

Environment

13. 62 submissions were received across a wide range of schools and departments; from very large to small and from long-established to relatively new entities. Overall 81 per cent (in volume weighted terms) of the environment submissions were assessed to be describing environments with vitality and sustainability conducive to producing research that is internationally excellent or better.

14. There was very clear consistency across a high proportion of the assessments made by individual sub-panel members. After agreement, uploading and acceptance of scores by the sub-panel, the following observations were made:

    a. It was evident that there had been extensive and sometimes significant strategic investment into restructuring of units during the assessment period, in some cases to facilitate interdisciplinary work, although the investment had not always gone into areas of world-leading activity. Investment in larger institutions was observed to include infrastructure. More general investment common to nearly all institutions tended to be in ECR recruitment and PhD training rather than capital equipment, rate of investment in which was thought to have slowed down – other than where there had been regional contributions made.

b. There had been a marked increase in the population of ECRs over the assessment period to now amount to 23 per cent of staff returned, and a noticeably more international staff profile was evident. The increased number of ECRs may have had the transient effect of reducing, in some cases, the number of outputs per FTE across the assessment period. The number of doctoral degrees awarded had increased to over 5,000 during the assessment period. The sub-panel felt it would have been interesting to have been able to identify the relative size of the overseas PhD community. The development of ECRs and training of PhD students was considered to be good. The sub-panel welcomed the inclusion of information on Athena SWAN status and, in particular, the institutions' positive responses to increasing diversity.

c. The research spend averaged almost £516,000 per FTE over the assessment period, emanating from a wide range of sources of research income, including RDAs, research councils, industry, government and international funders.

d. There was noted to be strong and growing national and EU collaboration but wider international academic collaboration was generally only more evident in larger institutions. There was evidence of significant research interaction and collaboration with national and international industries, with industrial funding contributing more than 20 per cent of the total research expenditure. However in several submissions it was observed that although there was an indication of industrial collaboration it was not always supported by sufficiently clearly-linked evidence of the impact of the research.

15. The sub-panel noted that there was some skew in the overall volume weighted environment profile in this UOA, as the seven largest submissions (which returned 42 per cent of the overall staff volume) scored very highly.

Glossary of terms

BIS

Department for business, Innovation & Skills

ECR

Early career researcher, defined in the REF as members or staff who meet the criteria to be selected as Category A or Category C staff on the census date, and who started their careers as independent researchers on or after 1 August 2009.

EPSRC

Engineering and Physical Sciences Research Council

EU

European Union

FTE

Full-time equivalent. Used as an alternative to headcount to indicate the actual volume of activity.

HEI

Higher education institution

HESA

Higher Education Statistics Agency

ICT

Information and communications technology

LMS

London Mathematical Society

MPB

Main Panel B

RAE

Research Assessment Exercise

RCUK

Research Councils UK

REF

Research Excellence Framework

SUPA

Scottish Universities Physics Alliance

UOA

Unit of assessment