Australian Academy of Science

PHYSICS DECADAL PLAN 2011/2012

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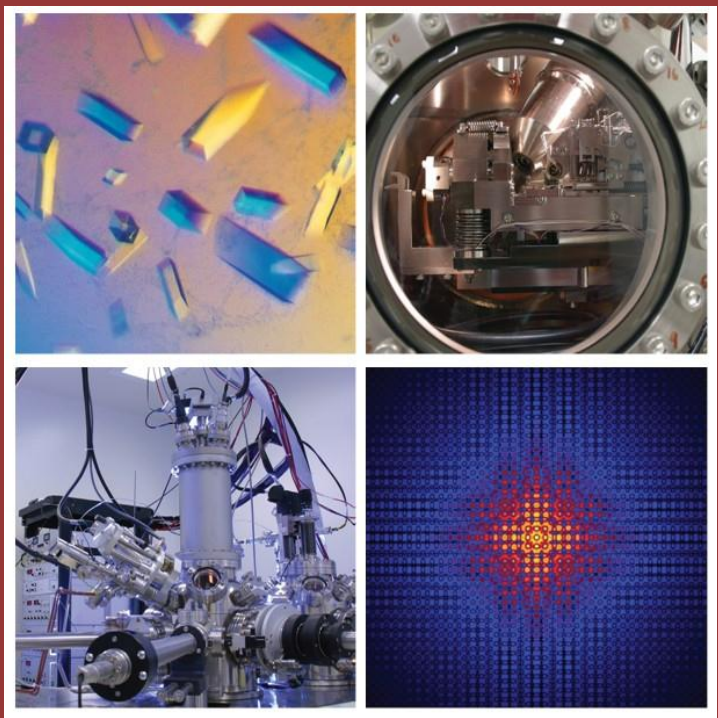
Underpinning Australia's future



Building on Excellence in Physics

Research Report

February 2012

The Physics Decadal Plan consists of two documents:

Part 1: Contains the executive summary, main recommendations and the reports on the sub-discipline clusters.

Part 2: Is this document. It contains the background and foreground research from which the findings presented in Part 1 have been drawn. The data in Part 2 can also be used for benchmarking future changes in the field.
It describes in detail the decadal plan process and includes much of the background research that fed into the plan. Part 2 also contains:

- A review of the current state of physics and the physics community in Australia in the context of the global and national operating environment.
- A description of the sectors of the physics community and opportunities for the future.
- Further in-depth information on the performance of each of the physics community sectors, based on secondary research that pulls together and analyses relevant publicly available information.

Both parts may be downloaded from the Physics Decadal Plan website:

http://www.physicsdecadalplan.org.au/

CONTENTS

EXECUTIVE SUMMARY 11
The physics community 11
Sector specific issues 12
The school education sector 12
The higher education sector 12
The research sector 13
Industry and business 13
The government sector 13
The domestic and international community 13
High impact opportunities 14
Opportunities in Education – creating a physics enabled workforce and community 14
Opportunities in research 14
Opportunities related to funding 14
Opportunities for internationalisation and cross-disciplinary collaboration 15
Opportunities for capturing the full human potential 15
Opportunities related to productivity 15
Opportunities for interaction with industry and business 15
BACKGROUND TO THE DECADAL PLAN 16
THE PLAN DEVELOPMENT PROCESS 20
Components of the plan process 20
Background stakeholder sector research 20
Consultation 20
Analysis and development of recommendations 21
Promotion 21
THE PHYSICS COMMUNITY AND ITS STAKEHOLDERS 22
The Australian physics community 22
The major stakeholder sectors 24
The school education sector 24
The higher education sector 24
Industry and business 25
The government sector 26
The general community 26
The international community 26
Critical success factors (CSFs) for a healthy physics community 26
THE GLOBAL OPERATING CONTEXT FOR PHYSICS 28
The contribution of physics to our society 28
The challenge of communicating the benefits of physics 29
The challenge of raising the awareness of physics 30
Physics in the global innovation system 30
External environment trends 30
Innovation trends 34
Australia's track record in innovation 35
Strategic direction of innovation in Australia 38
Strategic direction of innovation in other countries 40
Impact of physics on innovation 41
THE CURRENT GENERAL OPERATING ENVIRONMENT OF THE AUSTRALIAN PHYSICS COMMUNITY 45
Employment destinations for physicists 45
Professional representation of physicists in Australia 49
Australian physics community consultation and survey 50
Consultation, requirements identification and survey process 50
The current operating environment map 51

The physics community needs map 53
Consultation and survey conclusions 55
OUTCOMES OF SECONDARY RESEARCH ON PHYSICS COMMUNITY STAKEHOLDER SECTORS 57
The school education sector - primary and secondary education providers 57
Comparison to international benchmarks 58
Teachers and staff development for teaching 68
The higher education sector 74
Universities 76
Student mobility 89
Postgraduate education 92
PHYSICS RESEARCH AND FUNDING 97
Universities 98
Ranking of Australian physics in world tables 98
Physics research excellence rankings (ERA) 98
University competitive grant income 100
Research funding and the ARC 100
Success rates for proposals and gender equity in ARC funding 103
Specific funding issues 104
Downstream impact of university-based research 105
Centres of excellence, institutes and research centres 106
CSIRO 107
Defence Science and Technology Organisation (DSTO) 108
Australian Nuclear Science and Technology Organisation (ANSTO) 108
Cooperative Research Centres (CRCs) 109
Government service agencies 110
Health care providers 110
Bureau of Meteorology (BOM) 110
The National Measurement Institute (NMI) 110
The Australian Bureau of Statistics (ABS) 111
Other service agencies 111
Current physics research focus and global competitiveness 112
Cluster 1: Materials, energy and computing 112
Cluster 2: High energy, theory, nuclear and cosmology 114
Cluster 3: Photonics, quantum information, atom optics 116
Cluster 4: Applied physics 119
INTERNATIONALISATION OF PHYSICS RESEARCH 121
The international status of research publication 121
Australia as an international collaborator in physics 126
INDUSTRY AND BUSINESS 128
Industry and business segments that conduct R&D with the input and skills of physicists 131
Industry as a major employer of physicists 133
CAPTURING THE FULL HUMAN POTENTIAL 135
Women in physics 135
Productivity, career paths and metrics 138
ANALYSIS AND DEVELOPMENT OF RECOMMENDATIONS 142
SWOT analysis of the Australian general physics landscape 142
Strengths 142
Weaknesses 143
Threats 144
Opportunities 146
Trends and SWOT analysis of physics research 147
Trends in physics science and research 148
Research strengths 149
Research weaknesses 150

Research threats ... 152
Research opportunities ... 152
Sub-discipline needs ... 156
HIGH-IMPACT OPPORTUNITIES AND RECOMMENDATIONS ... 158
Research ... 158
Goals ... 158
Scientific opportunities for research ... 158
Research funding ... 160
Recommendations ... 161
Internationalisation and cross-disciplinary research ... 161
Systems to enable cross-disciplinary research ... 162
Recommendations ... 162
Education – Creating a physics-enabled workforce and community ... 162
Goals ... 162
Opportunities ... 162
Recommendations ... 163
Capturing the full human potential ... 164
Goals ... 164
Opportunities ... 164
Recommendations ... 164
Productivity ... 165
Goals ... 165
Opportunities ... 165
Recommendations ... 165
Interaction with industry and business ... 166
Goals ... 166
Opportunities ... 166
Recommendations ... 166
CONCLUSIONS ... 167

LISTS OF FIGURES, TABLES AND APPENDICES

List of figures

Figure 1 The major stakeholder sectors of the physics community 22
Figure 2 Strategic framework in which the Australian Physics community works. Arrows indicate direction of inputs into other strategies 23
Figure 3 Australia's innovation record 2010 36
Figure 4 Finland's innovation record 2010 37
Figure 5 Government contributions to business expenditure on research and development in OECD countries 38
Figure 6 Employment of physicists/mathematicians in 2007 and innovation activity over the previous two years in German industry companies 42
Figure 7 Employment of physicists and percentage of revenue from new products and services in German companies in 2008 43
Figure 8 Higher Education Funding to Universities 2000 to 2007. 75
Figure 9 Distribution of staff in Australian university Physics by seniority 79
Figure 10 University Physics Staff distribution by sub-discipline 80
Figure 11 Arrivals of university Physics staff by sub-discipline 81
Figure 12 Departures of university Physics staff by sub-discipline 82
Figure 13 Net change in university staff by sub-discipline 83
Figure 14 ARC funding for physics, indexed to CPI. (Source Hans Bachor, ANU) 102
Figure 15 Total ARC funding annualised. (Source Hans Bachor, ANU) 103
Figure 16 Percentage of Females by CSOF level 1995 - 2008 108
Figure 17 Relative impact of Australian scientific publications by field (2004 to 2008) Source: Australian Innovation System Report 2010 123
Figure 18 Proportion of Australian physics publications in Physical Review Letters by country 124
Figure 19 Number of publications by country in Applied Physics Letters 125
Figure 20 Number of publications by country in Optics Letters 125
Figure 21 Business expenditure on R&D, 1988-89 to 2007-08 129
Figure 22 Percentage of innovating businesses in 2008/09 129
Figure 23 Collaboration by industry with potential sources of innovation 130
Figure 24 Trends in the percentage of women in Physics education 137
Figure 25 Academic Profiles by Gender; Natural and Physical Sciences 2007 137
Figure 26 Government strategies for research workforce productivity increase 139

List of tables

Table 1 Critical success factors for a thriving, productive and effective Physics community 27
Table 2 Global trends with impact on Australian Physics education, research and industry 34
Table 3 Government research workforce strategies (Source: Research skills for an innovative Future. Commonwealth 2011) 39
Table 4 UK recommendation to increase the country's innovation and research competitiveness 40
Table 5 Job opportunities for physicists in the years 1984 to 2003 46
Table 6 Physics jobs on Seek on April 27, 2011 47
Table 7 Physics jobs in "Bright Recruits" for March and April 2011 48
Table 8 Percentages of students reaching international benchmarks in year 4 and Year 8 Science compared to a number of countries that ranked higher than Australia 60
Table 9 Average science scores for the science content domains for year 4. 61
Table 10 Average scale scores for the three cognitive domains for year 4 61
Table 11 Average scale scores for the four science subjects in year 8 62
Table 12 Average scale scores for the three cognitive domains for science in year 8 62
Table 13 Positive attitude towards Mathematics declining from year 4 to 8 63
Table 14 Positive attitude towards Science declining from year 4 to 8 63
Table 15 Proportion of Year 8 students valuing Mathematics 64
Table 16 Proportion of Year 8 students valuing Science 64
Table 17 Percentages of Australian students reaching international benchmarks in Year 4 and Year 8 Mathematics, in comparison with the major Asian neighbours and the international average. 65
Table 18 PISA 2009 Report: Performance of 15 year old students in various subjects comparing countries' and economies' performance 65
Table 19 PISA results for 15 year olds in international comparison from 2003 to 2009 by gender 66
Table 20 Reading proficiency levels of Australian 15 year olds from 2000 to 2009 67
Table 21 Mathematics proficiency levels of Australian 15 year olds 67
Table 22 Science proficiency levels of Australian 15 year olds 67
Table 23 Gender differences in top performance 67
Table 24 Percentage of students in year 4 and year 8 taught by teachers with various levels of qualification (by field of post-secondary specialisation) in Mathematics or Science 71
Table 25 Disciplinary background of junior school science teachers (n=598) 72
Table 26 Disciplinary backgrounds of the middle school science teachers (n=701) 73
Table 27 Australian Universities providing accredited Physics Bachelor of Science degrees 76
Table 28 Research Staffing Profile of Physics Sub-disciplines as reported in ERA 2010 77
Table 29 Proportion of university staffing across physics sub-disciplines in the ERA 2010 Research Excellence Assessment 77
Table 30 Student load 2002 – 2009: Teaching to students enrolled in courses at all course levels in All Fields of Education, by Discipline Group 85
Table 31 Teaching to students enrolled in courses at all course levels (undergraduate, Masters and PhD levels) in Natural and Physical Sciences, by Discipline Group 87
Table 32 Course completions of Natural and Physical Sciences (NPS) Students in NPS as Primary or Secondary Course 88
Table 33 Course completions of Natural and Physical Science Students for all course levels (undergraduate, Masters and PhD levels), by Citizenship Status 90
Table 34 Course completions of Natural and Physical Sciences Students for all course levels (undergraduate, Masters and PhD levels), by Gender 91
Table 35 PhD Student enrolments in All Fields of Education 93
Table 36 PhD Student Enrolments in Natural and Physical Sciences 93
Table 37 Teaching to students enrolled in PhD courses in Natural and Physical Sciences, by Discipline Group and Citizenship Status 94
Table 38 Teaching to students enrolled in PhD courses in the Natural and Physical Sciences, by Discipline Group and Gender 95

Table 39 Course completions: Natural and Physical Sciences Students – PhDs by Citizenship Status ... 96
Table 40 ERA 2010 ratings, Full Time Equivalents (FTEs) and research outputs ... 99
Table 41 ERA 2010 Research income and Impact measures ... 100
Table 42 Research funding via different university research income types during the three year period 2006 to 2008, according to ERA 2010 ... 100
Table 43 Number of ARC funded Physics research projects and funding allocation for the ten-year period from 2002 to 2011 ... 101
Table 44 ARC funds captured by physics ... 101
Table 45 Numbers and success rates for ARC Discovery Early Career Researcher Award proposals for funding commencing in 2012, by Disciplines ... 104
Table 46 Competition in the ARC senior fellowship schemes ... 105
Table 47 ARC Centres of Excellence with Physics involvement ... 107
Table 48 ANSTO performance indicators 2007/08 to 2008/09 ... 109
Table 49 Different models of industry collaboration with research providers ... 132
Table 50 Strengths that can be used to take advantage of trends and opportunities ... 142
Table 51 Weaknesses in the current Physics community operating system ... 144
Table 52 Threats to the health and operating processes of the Physics Community ... 145
Table 53 Opportunities for the Physics community and its sectors ... 147
Table 54 Trends in global Physics science and research ... 149
Table 55 Strength areas in Australian Physics science and research today. ... 150
Table 56 Weaknesses in Physics science and research ... 151
Table 57 Threats to Australian Physics science and research ... 152
Table 58 Opportunities in Australian Physics science and research ... 155
Table 59 Sub-discipline specific needs (not prioritised) ... 156
Table 60 Specific needs common to all Physics sub-disciplines ... 157
Table 61 Interview matrix ... 192
Table 62 Requirements related to culture of excellence ranked by opportunity score (Opportunity scores above 5.34 shaded yellow). ... 200
Table 63 Requirements relating to consolidation and collaboration within the tertiary sector, ranked by opportunity score. (Opportunity scores above 5.34 shaded yellow). ... 200
Table 64 Requirements relating to the need to address equity measures, ranked by opportunity score (Opportunity scores above 5.34 shaded yellow). ... 201
Table 65 Requirements related to the need to support temporary entrepreneurial engagements without prejudicing research career progression, ranked by opportunity score (Opportunity scores above 5.34 shaded yellow). ... 202
Table 66 Requirements relating to embracing applied physics research and commercial relationships, ranked by opportunity score (Opportunity scores above 5.34 shaded yellow). ... 202
Table 67 Requirements relating to closer and longer-term relationships between the Physics community and industry in targeted areas, ranked by opportunity score (Opportunity scores above 5.34 shaded yellow). ... 203
Table 68 Related requirements related to research tackling bigger problems with more adventurous approaches by opportunity score (Opportunity scores above 5.34 shaded yellow). ... 204
Table 69 Requirements related to research organisations needing to implement mechanisms that make working across disciplines easier, ranked by opportunity score (Opportunity scores above 5.34 shaded yellow). ... 205
Table 70 Requirements relating to better engagement with the school sector, ranked by opportunity score (Opportunity scores above 5.34 shaded yellow). ... 206
Table 71 Requirements related to better matching between undergraduate and postgraduate course content and employer requirements, ranked by opportunity score (Opportunity scores above 5.34 shaded yellow) ... 207
Table 72 Requirements related to the education of graduates and the needs to include more practical experience to increase employability, ranked by opportunity score (Opportunity scores above 5.34 shaded yellow). ... 207

Table 73 Requirements related to improving the relevance of performance metrics, ranked by opportunity score (Opportunity scores above 5.34 shaded yellow). 208
Table 74 Ranked list of all requirements by opportunity score 213

List of appendices

Appendix 1	Decadal Plan development timetable	170
Appendix 2	Terms of reference for the Decadal Plan working group for the National Strategic Review of Physics 2011	171
Appendix 3	Terms of reference for the Physics Decadal Plan sub-discipline working groups and their consultation and interview process	172
Appendix 4	Decadal Plan working group members	173
Appendix 5	Decadal Plan town hall meeting process and summary of contributions	175
Appendix 6	List of individuals and organisations consulted	186
Appendix 7	List of written submissions	189
Appendix 8	Sub-discipline reports	190
Appendix 9	Current general physics community operating environment, and needs survey	191
Appendix 10	ARC funding spreadsheets	214
Appendix 11	Higher education statistics spreadsheets	224
Appendix 12	AIP accredited courses	241
Appendix 13	Case studies	244

EXECUTIVE SUMMARY

Physics is an underpinning and fundamental field of science that makes essential contributions to society through new knowledge, new technology and skilled human capital. The last review of Australian Physics was conducted almost twenty years ago and since then many new discoveries have been made and the cutting edge research opportunities from twenty years ago have emerged to become mainstream research fields. An updated review of physics was seen as necessary to position the discipline for the next decade and beyond, and to take advantage of new opportunities that have arisen since the time of the previous review.

This physics decadal plan documents the impact of physics on the economic, technological, environmental and cultural development of Australia and presents a series of recommendations that, if implemented, would help ensure that physics continues to make a major contribution to Australia's development.

The plan development process was managed by the Physics Decadal Plan Working Group under the auspices of the Australian Institute of Physics and the Australian Academy of Science. Financial support was provided by the Australian Research Council and the Australian Institute of Physics.

There were four components to the formulation of the decadal plan. These were:

- Background stakeholder sector research;
- Consultation with the physics community;
- Analysis and development of recommendations on the basis of this information; and
- Promotion of the plan process.

The background research focused on the current state of physics in Australia. Relevant publicly available information on the external operating environment of physics, on the global and national trends in physics, and on the current performance of the major sectors that make up the "physics community" was compiled and analysed.

Consultation with the physics community was undertaken via a variety of mechanisms, including targeted interviews, "town hall" meetings, and invitation for submissions via the decadal plan website. The interviews provided information on the general state of physics and the physics community in Australia in the context of the global and national operating environment. They described the current issues and systemic problems that are experienced by the physics community as a whole and provided a prioritised set of general requirements for addressing these systemic problems.

The analysis of global trends, weaknesses and threats identified opportunities that will allow the physics community to use its strengths to strategically position physics for the next decade and beyond. This phase included workshops to agree the strengths to build on, the weaknesses to eliminate and the gaps and limitations that need to be overcome. The outcome of this strategic planning process was a number of recommendations for proposed implementation.

The physics community

There is no linear supply chain in physics, but rather a number of key stakeholder groups with specific and unique suppliers, customers and competitors. Each of the stakeholder groups and their customers and suppliers operate under specific local and global constraints unique to the Australian geographic location and the Australian political and regulatory environment. There are clear complementary relationships between the stakeholders and stakeholder groups.

A smooth and effective interaction between the various stakeholder sectors and an understanding of the changes within the operating environment, economic outlook and strategic imperatives of each stakeholder sector is vital for achieving a functional, vibrant and globally competitive physics community in Australia.

Sector specific issues

The school education sector

There are several issues that affect the education sector in Australia. Firstly, there is a low level of public awareness of the benefits of physics to society and therefore students show little interest to study physics, particularly as they do not see how the study of physics can apply to their lives and their future career choices. As well as the general lack of awareness surrounding physics, there are often negative perceptions of physics being too difficult and many students consider physics only as a prerequisite hurdle for entry into other courses. Positive school age experiences often shape the desire of students to study particular subjects. Therefore, the quality of physics teaching will influence the desire of students to continue studying physics in the final years of school and at university.

Two internationally benchmarked school student performance assessment vehicles, the Trends in International Mathematics and Science Study (TIMSS) which is repeated every 5 years and focuses on assessing performance in mathematics, physical, life and earth science at the Year 4 and Year 8 levels; and the Program for International Student Assessment (PISA) which is a comparative assessment of 15 year olds across the breadth of Reading, Mathematics and Science subjects, identified that Australian school students are currently performing below international benchmarks in science and mathematics.

The most recent TIMSS data is from 2007. The study showed that whilst the performance of Year 4 students has remained consistent, there has been a decline in the performance in mathematics, physical, life and earth science at the Year 8 level. Although Australian Year 4 students ranked above the world median, a number of countries that have emerged as the economic power houses of the Asia Pacific region, and also below the Russian Federation, England and the USA. Similarly, Australian Year 8 students ranked only just above the international median but well below students from its Asian neighbours, the Russian Federation and England. Physics was the science discipline in which students performed the poorest. Year 8 boys outperformed girls in both mathematics and science; less than a third of girls were at an advanced or high performance standard in science and one third of girls had not met or only just met the low performance standard.

The study showed that a positive attitude towards mathematics and science is correlated to a higher achievement in these subjects. In Australia, students' attitudes towards mathematics and science have declined between Year 4 and Year 8 both in an absolute sense, and even more dramatically relative to the international average

A feature of the school education sector is the lack of suitably trained science teachers at all levels of this sector. Nearly 43% of senior school physics teachers lacked a physics major, and one in four had not studied the subject beyond first-year. According to the TIMSS 2007 report, Australia's Year 4 students were taught both mathematics and science by teachers significantly less qualified than the international average. Physics was the weakest area in Australia for both Year 4 and Year 8, in terms of how well prepared teachers felt they were to teach this topic.

There is an opportunity to address the current gender imbalance that is already evident at the primary and early secondary school level to ensure that adequate numbers of women enter tertiary physics courses and ultimately pursue physics careers.

The higher education sector

Of the 30 universities that offer physics education in Australia, 19 have undergraduate courses accredited by the Australian Institute of Physics. Despite the often fierce competition between Australian universities with regard to attracting the best graduates and postgraduates for research, several of the tertiary institutions also collaborate and complement each other's activities.

The recent growth in physics undergraduate enrolments has come, to a large degree, from growth in the number of international students choosing Australian universities as destinations. Of the approximately 400 individuals who graduate each year with a physics degree, at least a quarter are international students. The higher education sector staffing profile shows a breadth of both teaching and experimental expertise across all sub-disciplines with peaks in astronomy/astrophysics, condensed matter physics and optics and photonics.

The higher education sector is dependent on the availability of high quality and capable entrants into the university system from schools and therefore is at risk of not able to produce sufficient numbers of graduates and trained researchers to satisfy the needs of all other stakeholder sectors if the current downward trend in physics education at the school level is not addressed.

The research sector

The 21st century promises extraordinary advances in our understanding of the fundamental questions in physics and in the application of physics to revolutionising our society. It is of key importance that Australian physics research continues to pursue research themes and questions that are of high scientific and global importance.

Australia has a vibrant physics research community and there are numerous examples of Australian teams that are making significant contributions to discovery and innovation as well as contributing to the global research effort through collaboration. Research in the physical sciences contributes substantially to the global rankings of Australian universities. The 2010 Excellence in Research for Australia (ERA) assessments demonstrate that Australian University physics research is a national strength. The amount of funding secured by physics research projects in universities through ARC grants is comparable to the level of measured research outcomes.

The research organisations of the Australian physics research sector are valued research partners in international research programs. Opportunities exist for the next generation of research leaders to continue to produce research outputs of equal excellence and impact if physics receives the continued support by Australian funding agencies through their competitive grant schemes and the support of large infrastructure.

Industry and business

Despite global industry being a major employer of physicists, compared to elsewhere in the world, there is generally low awareness in Australian industry of the usefulness and value of the contribution that physics skills make to an enterprise's success. Business and industry in Australia appear to have limited engagement with the other physics stakeholder sectors. There are, however, a number of successful models of industry collaboration with universities, for example in the mining, ICT and biomedical industries. Industry depends strongly on the higher education sector in Australia for the supply of graduates in addition to sourcing international graduates and employees from national and international companies. Industry and business has employment opportunities for Australian physicists and could benefit from a higher output of physics graduates.

The government sector

Government is a major employer of physicists, mainly in research and advisory roles in its major research and service agencies such as the CSIRO, DSTO, ANSTO, the Bureau of Meteorology and others. A major issue for government research and service agencies is the low number of available trained physicists graduating from university and entering a research career.

The domestic and international community

The domestic community expects that the education of their children by the school and higher education sectors will equip them with the knowledge and basic skills required to operate in a society in which technology is created and in which they will find employment. There is an opportunity for increasing the general physics awareness of the community through raising the standard of physics education in schools.

The international community's interest in the health of the Australian physics community is based on its ability to positively contribute to international debate and policy in a rational and scientific evidence based way. This requires that the standard of physics education from primary school to postgraduate education does not fall behind that of the remainder of the international community.

Australia is a well integrated player in the international physics community, with Australian physicists collaborating with many international teams, addressing the big research questions in physics. This international collaboration has enabled Australian physicists to capitalise on international investments made in existing research infrastructure that is often beyond the means of any single nation to build and maintain.

High impact opportunities

A number of high impact opportunities were identified through stakeholder consultation. They address the systemic needs of the physics community as a whole. The recommendations for achieving these opportunities are also provided.

Opportunities in Education – creating a physics enabled workforce and community

The greatest opportunities to achieve the overarching goal of a more physics-informed workforce and community and for increasing the number of young school leavers who want to study physics are seen through the invigoration of primary and secondary school physics education.

This invigoration of primary and secondary physics education, combined with appropriate mathematics education, will lead to positive domino effects in terms of increased competency and motivation of school students to study physics at a tertiary level. This in turn is expected to lead to positive effects of higher availability of skilled graduates for the higher education and research sector, industry, business and government.

High quality outreach programs by universities and research organisations is expected to have a high impact on reaching all Australians and raise their awareness for physics.

Opportunities in research

It is impossible to predict the origins of future high impact research and what new research directions will emerge. It is expected that all sub-disciplines will continue to contribute research outputs at a high excellence standard that will keep Australian research at the forefront of global physics research. A number of larger research areas currently continue to show exceptionally high activity: The new quantum revolution, the quest for new physics and symmetries, and physics transforming our lives. A fourth area of high activity relates to physics education.

Opportunities related to funding

Australian physics research has been very successful in attracting competitive funding. However, opportunities exist for expanding the breadth of funding schemes to cater for the specific needs of the physics research community. Specifically, there is a continued need to support large infrastructure including related technical support for maintenance and upgrading. There is also a need for investing in the creation of a Theoretical Physics Institute.

Opportunities for internationalisation and cross-disciplinary collaboration

There is opportunity to increase the competitiveness of Australian physics by investing in support for internationalisation of research groups and support for individual researchers who are working in international research teams. The continued support of Australian physics research groups that are part of international consortia is vital. There is also a need for supporting large cross-disciplinary research programs that address research questions of high complexity.

Opportunities for capturing the full human potential

Opportunities exist for enabling equitable access to career paths. The endorsement and consistent application of Research Opportunity and Performance Evidence (ROPE) principles in workplaces where promotion is based on research performance is an opportunity to make the intent of enforcing equitable access to research positions and career paths transparent. This may provide more incentive for women to enter and remain in a physics career.

Opportunities related to productivity

Opportunities exist to encourage funding agencies to simplify their funding processes to reduce the administrative burden and cost associated with preparing and assessing physics research proposals.

An expanded set of process and progress metrics in addition to the current publication-based metrics that evaluate how achievements track against organisational goals and milestones will be beneficial in allowing research organisations to analyse how they are progressing towards their strategic goals. Having access to a more expanded set of data will enable organisations to, for example, track their progress against funding and equity goals, monitor changes in physics discipline profiles in terms of attracting new talent, and gather information about the effectiveness of their outreach programs.

Opportunities for interaction with industry and business

Improved relationships with industry will allow the Australian research sector to develop and expand additional research collaborative arrangements, nationally and internationally in research areas that are compatible with the directions of Australian physics research.

A strategic approach to achieve more productivity in industry will require closer collaboration between industry and research organisations nationally and internationally. Further opportunities can be seen in strengthening interactions and scientific collaboration with cross-disciplinary teams, for example with engineering professionals, and the more applied physics sub-disciplines.

Strengthened relationships with industry will also highlight employment opportunities for graduates in industry and allow industry to identify talent and access capable graduates for employment.

BACKGROUND TO THE DECADAL PLAN

The purpose of the physics decadal plan is to review the current status of the discipline of physics in Australia, in the context of the environmental and operational constraints. This will enable:

- the setting of strategies to develop the necessary capabilities over the coming decade
- the next generation of Physics specialists to continue to contribute to the body of knowledge at an internationally competitive level
- seeding of the technology pipeline with new ideas, instruments and inventions
- Australian industry and service businesses to improve their innovation capability and global competitiveness.

The previous Physics Strategic Plan was written in 1993, almost 20 years ago. The state of physics today can be interpreted in light of that strategic plan. It needs to be understood that the impact of the activities of the last decade in research and teaching is only now becoming evident in terms of education outcomes and research performance and impact.

This Decadal Plan draws a baseline of the current state of physics in Australia. This has three reasons:

1. To allow the evaluation of the achievements of this plan in the future against the baseline metrics provided in this plan;
2. To allow the tracking of progress within the coming decade; and
3. To start building the analytics foundation that can become part of the information agenda of Physics as a discipline in the future.

Metrics play a crucial role in enabling change and adaptation to changing circumstances for any organisation, regardless of whether it is a commercially focused business or a publicly funded education or research organisation. A 2010 MIT Sloan Management Review/IBM research report[1] on the value of analytics to 3000 business and industry executives across a wide range of organisations found that those organisations that used more sophisticated analytics more extensively were performing better than those that did not. In addition, they used a broader range of metrics than the traditional focus on financial measures and dry numeric outputs.

To obtain a realistic understanding of physics as a discipline in Australia and establish a clear baseline that allows strategic planning and decision making based on meaningful metrics and analytics is not easy for the following reasons:

- Physics as a discipline spans a large number of sub-disciplines and provides value to many professions, organisations and industries;
- Different metrics are used in research organisations, government organisations and private enterprise;
- Beyond financial metrics, other metrics are not universally used or even applicable across all of the physics supply chain and within stakeholder organisations with interest in physics as a foundational or enabling discipline.
- Metrics relating to research performance, productivity and excellence differ from research organisation segment to segment. For example, those for the university segment may differ to those used by CSIRO or DSTO.

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[1] http://public.dhe.ibm.com/common/ssi/ecm/en/gbe03371usen/GBE03371USEN.PDF (2010) accessed April 25,2011

Effective operational and impact metrics are especially difficult to define and agree. If they are wrong, they drive the wrong behaviours.

The continuum of physics research and knowledge from basic and fundamental through to applied efforts at the border of technology and engineering is easier to discount than include. However, endeavours in these areas are essential components of the overall picture and contribution that Physics makes to the prosperity of the economy.

It would be easy, for the purpose of this plan, to dismiss applied physics research and focus on research activities that clearly deal only with the fundamental questions relating to the laws of the universe and its parts and particles, and perhaps limit this further by only considering research in the university environment. This report takes the view that a limited approach would also be limited in usefulness for the overall health of the physics community and supply chain, but necessarily therefore makes trade-offs in terms of the depth within which specific sub-disciplines are examined. However, some specific sub-disciplines, such as Astronomy, have developed a detailed strategic plan and other groups should be encouraged do the same. This report is not a substitute for that work. Consequently, this report attempts to cover the complete spectrum of physics sub-disciplines classified under Physical Sciences, as defined in the ANZSRC-FOR codes of 2008[2], which also includes Medical Physics. Where possible, it also addresses Mathematical Physics (which is currently listed under Mathematics), and Geophysics (which is currently listed under Earth Sciences).

The review of the discipline of physics is incomplete because of the lack of sophistication of analytics currently available, but it provides a starting position for the development of more harmonised metrics and the continuing update and tracking of the implementation of this decadal plan in the future.

The decadal plan for physics sits alongside several recent reports released by cognate agencies in other countries. Listed here are those with relevance to the present report together with their recommendations:

Scientific Century (2010)[3] – Royal Society, UK

The report makes six recommendations:

- Put science and innovation at the heart of a strategy for long-term economic growth
- Prioritise investment in excellent people
- Strengthen Government's use of science
- Reinforce the UK's position as a hub for global science and innovation
- Better align science and innovation with global challenges
- Revitalise science and mathematics education

Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future (2007)[4] – National Academies, USA

The report identified two key challenges that are tightly coupled to scientific and engineering prowess: creating high-quality jobs for Americans, and responding to the nation's need for clean, affordable, and reliable energy. To address those challenges, the committee structured its ideas according to four basic recommendations that focus on the human, financial, and knowledge capital necessary for the prosperity of the United States. The four recommendations focus on actions in K–12 education (10,000 Teachers, 10 Million Minds), research (Sowing the Seeds), higher education (Best and Brightest), and economic policy (Incentives for Innovation):

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[2] http://www.arc.gov.au/pdf/ANZSRC_FOR_codes.pdf Accessed April 26, 2011

[3] http://www.nap.edu/catalog.php?record_id=11463

[4] http://www.nap.edu/catalog.php?record_id=11463

- A: Increase America's talent pool by vastly improving K–12 science and mathematics education.
- B: Sustain and strengthen the nation's traditional commitment to long-term basic research that has the potential to be transformational to maintain the flow of new ideas that fuel the economy, provide security, and enhance the quality of life.
- C: Make the United States the most attractive setting in which to study and perform research so that we can develop, recruit, and retain the best and brightest students, scientists, and engineers from within the United States and throughout the world.
- D: Ensure that the United States is the premier place in the world to innovate; invest in downstream activities such as manufacturing and marketing; and create high-paying jobs based on innovation by such actions as modernizing the patent system, realigning tax policies to encourage innovation, and ensuring affordable broadband access.

Also provided are a total of 20 implementation steps for reaching the goals set forth in the recommendations.

Physics in a new Era[5] *– Board on Physics and Astronomy, National Research Council, USA*

This report was presented in 2001 and focused on the breakthroughs of 20th century physics that have "enriched science and opened a new era of discovery". It identified six research priority areas:

- Developing Quantum Technologies
- Understanding complex systems
- Applying physics to biology
- Creating new materials
- Exploring the universe
- Unifying the forces of nature

The report makes nine recommendations:

- Invest in physics
- Revise curricula in physics education to ensure engagement and make connections to other important areas of science and technology.
- Provide adequate and stable support for small groups and single investigators
- Plan on supporting large facilities and international collaborations
- Continue support for physics in national security
- Encourage partnerships between government, industry and universities
- Support creative research by federal agencies
- Maintain peer review
- Coordinate physics information processes and archives.

Within Australia, the recent "*A decadal Plan for Australian Astronomy 2006-2015*"[6]and the "*Mathematics and Statistics: Critical Skills for Australia's Future*"[7] from 2006 were also influential. The mathematics plan painted a very bleak picture of the state of mathematics and statistics in Australia and made the following observations:

- Mathematics research in Australia is becoming increasingly narrowly focused.

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[5] http://www.nap.edu/catalog.php?record_id=10118
[6] http://www.science.org.au/natcoms/nc-astronomy/documents/DecadalPlan_print.pdf
[7] http://www.review.ms.unimelb.edu.au/Report.html

- The number of mathematics and statistics students and lecturers at Australian universities is critically low.
- Mathematicians and statisticians are not teaching all the university courses in mathematics and statistics. Many university courses such as engineering that should include a strong mathematics and statistics component, no longer do.
- Not enough trained mathematics teachers are entering the high school system. Australian students are abandoning higher-level mathematics in favour of elementary mathematics.

The report makes the following recommendations:

- Significantly increase the number of university graduates with appropriate mathematical and statistical training.
- Broaden the mathematical sciences research base. Identify, anticipate and meet industry needs for a pool of tertiary-trained expert mathematicians and statisticians.
- Ensure that all mathematics teachers in Australian schools have appropriate training in the disciplines of mathematics and statistics to the highest international standards.
- Encourage greater numbers of high school students to study intermediate and advanced mathematics.

The "*Australian Plan to Develop a Science of the Whole Earth System*"[8]. This report identified the overarching global Earth system issue:

- How can we secure a well-functioning and resilient Earth system for the indefinite future?

This leads to the challenge of achieving a stable balance between the needs of the people on Earth and the physical and biological limits of our planet. The report then identified the most important science questions and the means needed to address these questions.

The challenge for the physics decadal plan working group was to devise an appropriate framework for presenting a decadal plan for physics, given the diversity of approaches employed in these prior reports and the diversity of physics sub-disciplines and strategic research directions.

[8] http://www.science.org.au/natcoms/nc-ess/documents/ess-report2010.pdf

THE PLAN DEVELOPMENT PROCESS

The development of this physics decadal plan was chaired by Professor David Jamieson of the School of Physics at the University of Melbourne and was guided by the Physics Decadal Plan Working Group. It was further supported by five sub-discipline groups that were broadly grouped into the following clusters:

Cluster 1: **Materials, energy and computing**—including condensed matter and materials physics; energy and power technologies; chemical physics; and supercomputing.

Cluster 2: **High energy, theory, nuclear and cosmology—**including particle physics; theoretical and mathematical physics; nuclear physics; astronomical and cosmological physics; and plasma physics.

Cluster 3: **Photonics, quantum information, atom optics**—including optics and photonics; quantum information and computation; and atom optics.

Cluster 4: **Applied physics—**including medical physics and biological physics; industrial physics; climate and atmospheric physics; hypersonics and fluid mechanics; geophysics; and acoustic physics.

Cluster 5: **Education**—education and outreach.

Components of the plan process

The Decadal Plan process consisted of four broad components:

- Background stakeholder sector research
- Consultation
- Analysis and development of recommendations
- Promotion of the plan process

Background stakeholder sector research

This component focused on the current state of physics in Australia. It consists of pulling together and analysing relevant publicly available information on the external operating environment of physics, on global and national trends in physics, and on the current performance of the major sectors that make up the "physics community".

Consultation

This component is a large body of primary research derived from interviews of individuals throughout the physics community and stakeholder sectors. One set of interviews provided information on the general current state of physics and the physics community in Australia in the context of the global and national operating environment. It describes the current issues and systemic problems that are experienced by the physics community as a whole and provides a prioritised set of general requirements for addressing these systemic problems. A second set of interviews provided information on the current state of physical science and research in Australia and the problems and issues that are currently encountered, and requirements for addressing these issues.

The process of reviewing the state of physics in Australia today included the following steps:

1. *Town hall meetings:* A town hall style meeting at the 2008 AIP Physics Congress in Adelaide and four similar meetings at the 2010 AIP Physics Congress in Melbourne. The town hall meetings were arranged according to sub-discipline clusters. The summaries of these meetings are provided in Appendix 5.
2. *General Physics requirements interviews*: In-depth individual interviews were undertaken with 65 individuals (see Appendix 6) across the Physics stakeholder groups to uncover the general and systemic strengths, weaknesses, threats and specific general requirements for maintaining and increasing the capabilities in physics education, research and related areas.
3. *White Paper Submissions*: The physics community was encouraged to submit white papers through a dedicated white paper submission page on the physics decadal plan website http://www.physicsdecadalplan.org.au or to make any other contributions and suggestions via email to the Decadal Plan Working Group. A list of the submissions is provided at Appendix 7.
4. *Physics research requirements interviews*: To uncover the achievements, strengths, weaknesses, limits and barriers within the many sub-disciplines, the sub-discipline working group chairs and members conducted a number of structured interviews and informal meetings and discussions within the sub-disciplines of their cluster. The complete sub-discipline cluster reports are provided in Appendix 8.

Analysis and development of recommendations

The consultation phase was also used as the bridge to the third phase of the decadal plan development process, the forward looking component that identified emerging opportunities to be highlighted and developed. The analysis of global trends, weaknesses and threats identified opportunities that allow the physics community to use their strengths to strategically position physics for the next decade and beyond, such that it contributes even more positively to the competiveness of Australia's science and research, the technology industries and the economy.

This phase included workshops to agree the strengths to build on, the weaknesses to eliminate and the gaps and limitations that need to be overcome. The outcome of this strategic planning process is a number of recommendations that are listed for proposed implementation.

Promotion

The decadal plan process was promoted to the physics community through several channels including:

- The AIP Physics Congresses in 2008 and 2010;
- An update in each AIP newsletter that is delivered electronically to the AIP membership;
- Encouragement of each of the interviewees to promote participation in the plan development process through their specific affiliations, via professional newsletters, media and other contacts;
- Individual presentations from the Chair and members of the Physics Decadal Plan Working Group to physics departments and to other organisations such as, for example, CSIRO, DSTO, Universities and other interested groups;
- The physics decadal plan website, which was used to keep the stakeholder community up to date with the process and the submitted and produced materials.

THE PHYSICS COMMUNITY AND ITS STAKEHOLDERS

The Australian physics community

The Australian physics community is the combined grouping of the major stakeholder sectors, as shown in Figure 1.

It operates in a competitive global environment under specific local and global constraints unique to the Australian geographic location and the Australian political and regulatory environment.

Each of the sectors is discussed in greater detail further on in this plan.

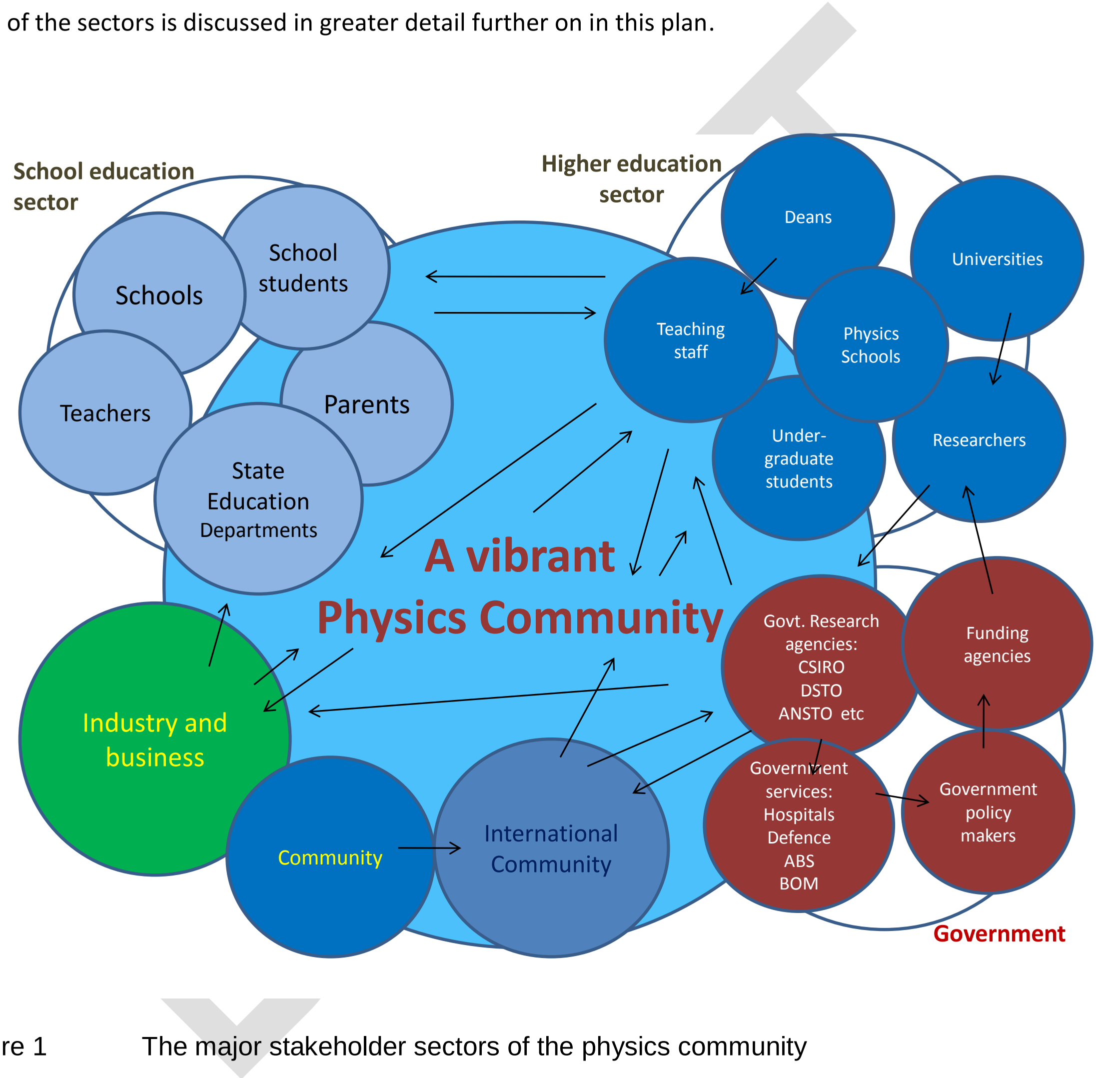

Figure 1 The major stakeholder sectors of the physics community

A smooth and effective interaction between the various stakeholder sectors and an understanding of the changes within the operating environment, economic outlook and strategic imperatives of each stakeholder sector is vital for achieving a functional, vibrant and globally competitive physics community in Australia. For example, the focus and direction of the Australian physics education and research strategies is, to a large extent, provided by the innovation and research strategies of the Australian government.

The operating environment is determined to some degree by budget allocations to education institutions, funding agencies and research providers in competition with other uses of government funds, and by the rules governing use of the funds. Within each of the stakeholder sectors additional strategic imperatives play a role in tempering the environment in which the government's high level goals are expected to be addressed. The resulting strategic framework in which the physics supply chain operates has many different stakeholder groups with potentially conflicting strategic goals (Figure 2).

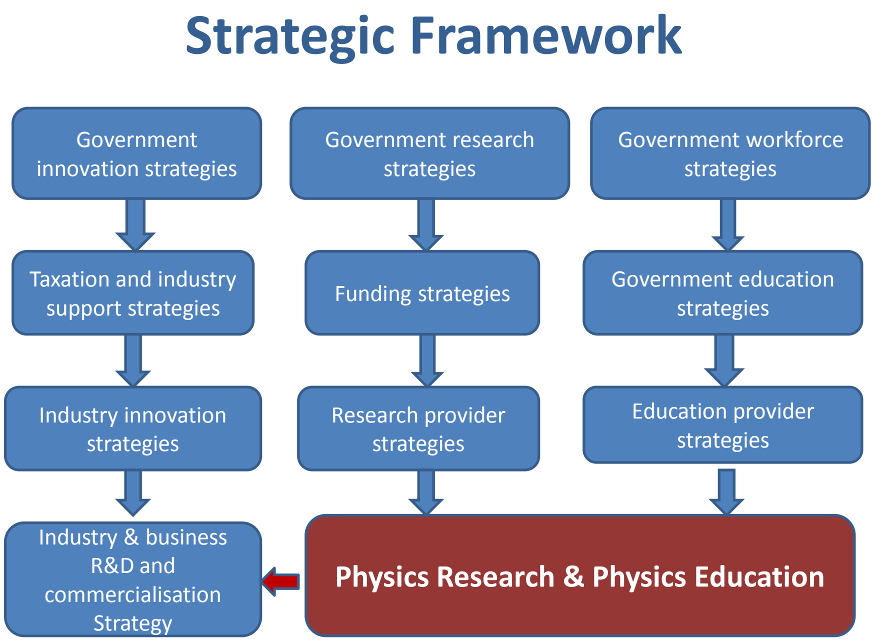

Figure 2 Strategic framework in which the Australian Physics community works. Arrows indicate direction of inputs into other strategies

Accurate numbers of physicists in Australia are not available and the estimates of the number of employed physicists given below could not be substantiated by the majority of the employing entities shown, but could be greater than 6,000. They are seemingly ubiquitous, but invisible!

University system:	900 (estimate)
CSIRO	500 (estimate)
ANSTO	100 (estimate)
DSTO	between 200 and 400
BOM	90 (estimate)
ABS	unknown
Physics teachers	2700*(estimate)
Government	unknown
Medical Physicists	500 to 600 (estimate)
Industry/business based	unknown but likely >1000.

*Based on the numbers of secondary schools (1409) and combined primary/secondary schools (1286) in Australia[9] and on the assumption that each school would have at least one teacher teaching physics.

[9] http://www.abs.gov.au/AUSSTATS/abs@.nsf/mf/1330.0#article%209

The major stakeholder sectors

There is no linear supply chain in Physics, but rather a number of key stakeholder groups with their specific and unique suppliers, customers and competitors. There are also clear complementary relationships between the stakeholders and stakeholder groups. Each of the stakeholder groups and their customers and suppliers operates under distinct sets of rules and constraints.

The major stakeholder groups included are:

- The school education sector;
- The higher education sector;
- Industry and business;
- The government sector;
- The general community;
- The international community.

The school education sector

The stakeholders engaged in creating and delivering value in the pre-primary, primary and secondary school sector are the teachers and the schools in which they teach. They are tasked to deliver physics education to students that satisfy the expectations of all the school education sector customers (students, parents, employers, tertiary education institutions, and government).

School physics education is expected to provide students with the skills needed in their working lives and/or for passing tertiary education entry requirements if the student wishes to enrol in a tertiary course that requires physics as a prerequisite. The education students receive is also expected to allow them to reach a level of physics literacy that permits them to take part in debates on, for example, questions of common interest such as energy security and climate change.

Schools operate under state and federal government rules and legislation. Suppliers to schools are teachers, book publishers, on-line services, computer hardware and software suppliers, as well as donors including parents. Competitors to Australian schools as educators in physics do not exist other than in the form of competition within the system for other science disciplines such as biology, chemistry or non-science education.

Schools, other than private schools, do not actively compete with each other to attract students who want to study physics.

The higher education sector

The higher education sector's main outputs are graduates (BSc and BEd) trained in Physics; trained researchers (Masters, PhDs, Postdocs); and new knowledge delivered as publications, conference papers, books and intellectual property. Its customers are students; parents; industry and business; federal, state and local governments as funders of the sector's activities as well as employers and as funders of major federal research agencies (such as for example CSIRO or DSTO). A major customer segment that has emerged over the last two decades is that of international students and their parents and governments. However, there are no data that indicate that Australia is a particularly preferred destination for higher education in physics, compared to other countries.

The suppliers to the sector are publishers, scientific equipment suppliers, hardware and software suppliers, online services, faculty, administrative staff, and donors.

Although there is competition within the sector in Australia, there is little differentiation between physics curricula at the undergraduate tertiary education level. However, at the postgraduate research training level there is more diversity, based on the research strengths of each university. Of the 30 universities that offer physics education in Australia, 19 have undergraduate courses accredited by the Australian Institute of Physics.

Competition for Australian tertiary institutions increasingly comes from international education providers that perform well in international rankings and can provide lower cost education. This is compounded by a strong Australian dollar. However, the main competitors to physics tertiary education are courses from other disciplines e.g. biology, engineering, chemistry, medicine, environmental sciences. Although these disciplines require physics as an enabling science, they increasingly use in-house resources to teach physics. This practice is exacerbated by student based funding models that have resulted in a decrease in physics service teaching to other disciplines.

"It was compulsory in Czechoslovakia that in line with your physics subjects you had to have at least one general subject, such as economics, because they consider that as a university graduate you will be someone who will be running the country in your specialty or department or something so you do need that general knowledge as well"

Although competition between Australian universities is fierce, especially with regard to attracting the best graduates and postgraduates for research, many of the tertiary institutions also collaborate and complement each other's activities.

Many other complementary service providers are not specific to the physics community. However, they can make a difference in the choices student, academic staff and research talent make for study and work destinations.

Industry and business

Apart from the mining industry and the scientific instrument industry that employ physicists with specific skills, there is generally low awareness in Australian industry of the usefulness and value of the contribution that physics skills make to enterprise success.

This contrasts with the US, where more than 50% of physics graduates find employment in industry and business, or Germany, where Physics is regarded as a "power tool set" for driving innovation and where the number of physicists employed in R&D and production by industry (excluding software development) also exceeds the number of those employed in higher education and research organisations. Sixty per cent of German industry physicists are found in manufacturing companies, 22% in Software companies and 18% in service companies. They are found in engineering, planning, and management and leadership roles, from technician level up to company directors.

By contrast, business and industry that relates to physics in Australia is predominantly engaged in complementary roles to the other stakeholder sectors such as the school (e.g. teaching and publishing) and higher education sector (teaching and research, instrument supply), and to the government sector (e.g. defence) as a supplier of services and products.

Competitors to Australian industry companies are global in their specific sectors. Suppliers to the Australian industry are the higher education sector in Australia and internationally through the supply of graduates, and other industry companies both nationally and globally. This fact is demonstrated by the ongoing sourcing of physicists from former Eastern Bloc countries, especially by the mining and high tech scientific instrument industry sectors.

The rules of operation for industry are generally determined by government legislation such as R&D taxation rebates and regulations directed at building and industry competence and competitiveness.

The government sector

The government sector's involvement in the physics community is generally in a customer role, through setting of national research and innovation policy and through related funding allocations to both the higher education sector (universities) and the research sector (universities through funding agencies, and government research agencies such as CSIRO), but also through the employment of physicists in government funded and managed research organisations such as CSIRO, DSTO, ANSTO and in service organisations such as the Australian Bureau of Statistics (ABS), the Bureau of Meteorology (BOM) and the National Measurement Institute (NMI). These organisations employ physicists both in their service and their research functions.

The value derived from the employment of physicists in federal, state and local government agencies is related to their numeracy and specific subject matter skills but also to their problem solving skills. For example, physicists can be found in treasury, in strategic advisory and policy roles and in representative and advisory roles on international panels.

The general community

The general community is interested in physics because of the knowledge and wealth created through funds spent on physics education, research and commercialisation. As a stakeholder group overall, the community clearly has a demand for information that spells out the benefits of funds spent. As customers of the education sector specifically, the community expects that the education of their children will equip them with the knowledge and basic skills required to operate in a society and economy in which technology is created and in which they will find employment.

In contrast to some European countries, for example France, where the pursuit of science and physics is seen as a valuable pursuit in its own right, in Australia it is harder to communicate the value of investing in physics purely for the purposes of expanding the boundaries of knowledge and creating fundamental scientific breakthroughs.

The international community

The international community's interest, in the health of the Australian physics community is based on its ability to positively contribute to international debate and policy in a rational and scientific evidence based way. This requires that the standard of physics education from primary school to postgraduate education, does not fall behind that of the remainder of the international community. It also requires that Australian physicists are able to provide inputs on international panels and agencies that develop international policy.

Critical success factors (CSFs) for a healthy physics community

The CSFs for *any* country that wants to remain or become highly successful and globally competitive in physics education, research and development, and that aims to create a knowledgeable population and economic wealth are listed in Table 1. This list is therefore applicable to the Australian physics community.

A thriving, productive and effective physics community requires that each sector understands and contributes to the achievement of each other's CSFs. It also requires that each sector understands the customer-supplier relationships within the whole physics community and the rules by which each of them operates.

Contributors to the Physics' Landscape	Critical Success Factor (CSF)
Schools (primary)	Teacher training to include a strong science and maths components; Ongoing support and teaching resources that are age appropriate
Schools (secondary)	Trained physics and maths teachers (trained at 3 years higher than level they teach) & appropriate infrastructure/resources; Students interested in studying physics at school; students aware of the relevance , applications and career opportunities in physics
Higher Education	Students who are appropriately qualified wanting to study physics in Australia; Related disciplines motivated to source physics service teaching from physicists; Excellent and inspiring physics teaching
Research	Vibrant research community that generates new ideas; Excellent research infrastructure and resources to attract research talent; Predictability of funding to attract and retain talent and take research risks that don't depend on short term funding cycles.
Funders	Return on investment (relative to other investment options)
Government	Improved productivity/economic wealth, employment, country competitiveness attributed to funding; improved international status; improvement in national capabilities and expertise
Industry	Access to IP that improves their competitiveness and profitability; Trained future employees; Access to research assets that they wouldn't buy themselves/contract research capacity; favourable conditions for operations in the country
General Public	Knowledge to better participate current debates, benefit of applied IP (to society), education for their children; understanding of the universe (origin, evolution and fate!)
International Community	Access to expertise, collaboration, leverage of their capabilities; ability to address bigger questions that can't be solved in isolation; access to high quality education & research training

Table 1 Critical success factors for a thriving, productive and effective Physics community

THE GLOBAL OPERATING CONTEXT FOR PHYSICS

Physics, as one of the “Natural and Physical Sciences”, involves the study of matter and energy in time and space and how they interact with each other. Physicists discover the rules of how the universe and its parts work and behave, from the sub-atomic particles to the largest galaxies in outer space. Physics has many sub-disciplines that have evolved over time as more and more knowledge accumulated within specific fields.

Physics is, along with Mathematics and Chemistry, one of the foundation and enabling sciences for other sciences such as, biology, medicine, earth sciences and their sub-disciplines.

Astronomy may have been the science discipline that originally endeavoured to understand how the world functions within the then known universe. In so doing, astronomers discovered not only some of the fundamental physical laws and rules that govern the universe, they were also instrumental in developing the tools for further discoveries and expansion of physical knowledge. Today, Astronomy is a huge field of research, discovery and related development of measurement instruments that enable the further exploration of the universe. However, it is now only one of the many sub-disciplines of physics, even though it can be considered as a stand-alone scientific discipline. Many of the currently defined physics sub-disciplines, such as medical physics or geophysics, have developed identities away from “mainstream physics”. Even within mainstream physics, new sub-disciplines such as quantum physics are continuously evolving, emerging and expanding.

The expansion of knowledge in physics has been greatly facilitated by the development of sophisticated and powerful measurement tools and infrastructure such as synchrotrons, radio-telescopes, lasers, neutron sources and super-computing facilities. These instruments and concepts, originally developed by physicists, have not only enabled new discoveries in physics but also in other sciences such as chemistry, biology and medicine.

The resulting closer collaboration between physicists and scientists in other disciplines has resulted in the recognition that the boundaries between physics and some of the other sciences are blurred. Interdisciplinary fields of science are emerging at a rapid rate, for example, neurophysics, nanomaterials science and econophysics.

“Physics is the king and queen of all sciences that really brings you closer to nature, closer to the universe to give you the answers as to how the world functions”

Medical Physicist

The contribution of physics to our society

Through the need to expand the boundaries of fundamental science, physicists have developed new experimental and measurement instruments and techniques. These new instruments and techniques have often then been the sources of new technology based industries, such as the modern information and communication industry, the internet and computer hardware and software technology based industries.

Much of today’s media and entertainment technology would not have been possible without physicists. Modern medicine has benefitted from the development of lasers, radioisotopes, CT and MRI scanners for medical imaging; discoveries made by physicists, often several decades before these technologies became mainstream diagnostic and therapeutic tools.

The recognition of the usefulness of these original ideas and physics laboratory instruments by inventors, engineers, clinicians and others led to further development into usable prototypes, viable and profitable products and eventually to new industries.

This seeding of the technology pipeline is one of the characteristic strengths of the physics discipline, but for the translation of the seeds into viable and profitable concepts and products, the discipline relies on a functioning interaction with the downstream disciplines of other natural sciences, engineering, profitable industry and a business environment that values science and innovation.

Australian physics was very successful in the first few decades after World War II, with many key achievements emanating from defence related research and development. Since that time, it has become increasingly difficult to maintain competitiveness, and success necessitates global collaboration. This is driven by the rising size and cost of instrumentation and resources required to address the most important physics research questions. Examples are CERN, the proposed Square Kilometre Array, LIGO, accelerators, neutron sources and synchrotrons, as well as supercomputers.

The following are a small selection of recent achievements by the Australian Physics community that were identified during the decadal plan interview and consultation process:

- Wireless LAN;
- The development of scalable quantum computing technologies, namely in optical quantum computing;
- The emergence of a third stream of research based on computer simulations alongside the traditional theory and experimental streams, enabled by the advent of very powerful computer resources over the past decade;
- Supercomputers;
- The Australian FEDSAT program;
- The Cochlear implant;
- Infrared micro spectrometers based on optical micro-electromechanical systems (MEMS) finding applications in defence and agriculture;
- Ability to monitor the earth's atmosphere and measure the influences of human activity on the atmosphere and climate.

The challenge of communicating the benefits of physics

Although physics as a technology-seeding discipline has been critical for our current high quality of life and much increased lifespan, it is difficult to communicate the value of the investments made in physics related research and education and research infrastructure because of the very delayed realisation of the benefits from these investments.

Society takes current gadgetry for granted and expects improvements to evolve, for example new and cheaper models of MRIs, lasers, laptops, more powerful supercomputers, and faster internet speed. The original source of all these technologies is rarely acknowledged. Even if society knew which physicist developed a technology, it would have little or no understanding of the educational and knowledge inputs that made it possible and delivered demonstrable benefits for society.

There are several examples of physics based technologies developed in Australia that led to advances in aeronautical, medical, mining exploration, defence and communication technologies in many industries. For example, the FALCON gravity gradiometer technology and CSIRO's LANDTEM are two examples of applying the laws and principles of physics in the development of new instruments for the purposes of mineral exploration. Both the FALCON project and the LANDTEM project started in 1991. The value of these technologies to mineral exploration is considerable. Both technologies cut millions of dollars of exploration costs and allow mineral resource companies to reap the benefits of more accurate exploration much earlier than with more conventional exploration methods such as exploratory drilling. The value of these two technologies to the companies using them is in the order of billions of dollars. However, in most cases, it is difficult to put a dollar value on technologies that are based on physics research and knowledge. This is because additional innovation and commercialisation processes, and bundling with other technologies are typically required to turn ideas and research results into technologies and services that can be used and sold.

The challenge of raising the awareness of physics

Despite the critical role of Physics for the wellbeing of society, the discipline receives little attention by the public and the media in Australia. In mid-2011 a search of the word "Physics" on the website of a major national newspaper did not reveal any hits; however, for the same time interval "Chemistry" returned more than 1000.

A 2008 OECD Global Science Forum workshop on improving the dialogue with society on scientific issues[10] stated that "preserving and promoting the benefits of research is a shared responsibility of all stakeholders from government, industry, the research enterprise, and civil society. Today, citizens are constantly and deeply affected by science and technology – due to the success of science! One has merely to compare one's life with that of one's parents or grandparents to appreciate the huge transformations in the fields of medicine, transportation, communications, housing, etc. But there is a significant new trend: the changes are no longer accepted as automatically beneficial. Trust in science is decreasing in many industrialised countries, among young people and the public in general, as indicated by numerous surveys. .... In response to the growing concerns, numerous public debates have taken place, in many forms and in more or less institutional ways, but to date they do not seem to have had a major effect on the diminishing public trust in science."

Physics as a discipline has special challenges in conveying the importance of the discovery of new knowledge and laying the foundations for new technologies that benefit society.

The existence of a chemical industry and the everyday use of 'chemicals' such as detergents, fertilisers, dyes, paints etc. is 'understood' even by primary school children. As there is no specific 'physics industry' and the term 'physics' is often introduced only at high school level, it is much more difficult for children and their parents to understand why they should invest time, effort and money in gaining knowledge in the discipline of physics. The lack of specific "physics jobs", besides those in the academic or research environment, makes it more difficult to raise the visibility of physics as a springboard to lucrative employment opportunities across many industries. For example, there are limited visible examples of physicists in careers such as mining, engineering, communication technology companies, medical device companies, hospitals, materials design companies, defence agencies, the Bureau of meteorology and in policy making, yet all these industries employ physicists and value the skills they contribute.

"We suddenly realised that people don't believe evidence, people don't believe scientists anymore. They don't trust us. That whole architecture of trust and where it comes from, we need to look and understand where that comes from. We as scientists have failed abysmally. That is really vital not only for the planet to survive but also for building the status of science in society."

Delegate at the 2010 AIP Physics Congress

Physics in the global innovation system

External environment trends

The Australian physics community operates in the global environment and is subject to the impact of global trends. Over the next decade or two, some of these trends will provide both opportunities and threats for Australian physics.

[10] Improving the dialogue with society on scientific issues. OECD 2008 http://www.oecd.org/dataoecd/18/37/42887346.pdf

As summarised in Table 2, the external environment is highly supportive of future growth for physics. However, key trends will influence where in the world the growth will take place. Australia has the potential to be well positioned to exploit these trends and take a technology leadership role through new disruptive technologies. Australian physics can play an important role, but to play this role it has to step out into a universe of risky ideas, new partnerships, fundamental research and aggressive commercialisation of research outcomes.

Economic trends – a global shift in economic powers that requires Australia to realign its thinking about future partnerships to take a leadership position in the region
• Economic power will be concentrated around the Pacific Ocean: North America, Oceania, North and South East Asia will get 67% of the world GNI[11]. • Shift in relative wealth and economic power from west to east will continue with the rising economic power of the 'Asian Tigers' and other countries in the Asia Pacific Region.[12] • Continued economic growth globally in combination with population growth will put pressure on natural resources but will drive innovation in technology • By 2030 the demand for food will rise by 50% by World Bank expectations. • Some oil-rich nations are re-focusing from exploitation of natural resources to education and innovation. • Interest rates, exchange rates, decrease in disposable incomes, higher food prices will determine the numbers of students taking up tertiary education and the countries they choose as study destinations.
Demographic trends – the need to feed, clothe, house and educate an increasing global population, requires new technology solutions
• Global population increasing. The ten most populated countries with 63% of the world's population in 2030 are expected to be: India (1,449 million), China (1,346 million), the European Union enlarged to Balkans and Turkey (605 million), the USA (360 million), Indonesia (270 million), Pakistan (262 million), Brazil (235 million), Nigeria (217 million), Bangladesh (205 million), and Ethiopia (136 million) • Ageing demographics in developed countries and health issues due to lifestyle and diet will lead to higher health care expenses and downward pressure on education and research and innovation spending. • High fertility rates in some developing countries combined with starvation and health related issues may lead to political unrest and low priority for education and research and development • Ageing academic workforce will lead to reduced economic growth in some countries (e.g. some European countries and Japan) will reduced demand for new products. • Immigration trends in some global regions will lead to ideological and religion related stresses and potentially to changing education requirements.
Geopolitical and legal trends – varied approaches to management of global economics, resources and science and education provides both opportunities and threats
• Power shifts to Asia, especially China. • No other countries are projected to rise to the level of China, India, or Russia, and none is likely to match their individual global clout. It is expected that the political and economic power of other countries - such as Indonesia, Iran, and Turkey – will increase. • Concurrent with the shift in power among nation-states, the relative power of various non-state-actors such as businesses, tribes, religious organizations, and criminal networks will increase by 2025. • The influence of the US will decline but by 2025 they are still expected to be the most powerful nation globally. • Increased protectionism, potentially also in the direction of resource nationalisation and rationalisation. This could drive technology innovation to reduce dependencies.

[11] http://www.freeworldacademy.com/globalleader/trends.htm
[12] Global Trends 2025: A Transformed World. National Intelligence Council. November 2008 www.dni.gov/nic/NIC_2025_project.html

- Increased efforts to compete in education ranking tables by most countries for national status and demonstration of competitiveness.
- 'Voice of science' not heard by the general public and decision makers in many countries. Political decisions based on intuition, religious beliefs, ideology or potential attractiveness to voters.
- Increased implementation globally of carbon taxes.
- Country differences in R&D tax legislation for business and industry will advantage and disadvantage some countries.
- International agreements on climate and environmental regulations will require technology innovation
- Increased focus on clean energy will lead to specific legislation.
- Legislation relating to school education and equality.
- Legislation relating to higher education will differ by country affecting study destinations
- Country specific legislation and regulation will affect industry in terms of innovation speed and cost
- 'Dirty' manufacturing and waste disposal will be unacceptable in increasing numbers of countries

Environmental trends – globally recognised critical issues that require new solutions

- Depletion of natural resources combined with increased demand will lead to the need to do more with less. There will be a need for more resource efficiency[13]
- Climate change will require new technologies for research, modelling and prediction of systemic changes and their impact in both the atmosphere, on land and in the ocean environment. This will require new measurement instruments, more advanced super-computing powers and development of models.
- Increased impact of more frequent and severe adverse weather events with higher insurance and rebuilding costs will put downward pressure on government, business and private spending on education, and research and development and on increased business spending through increased insurance premiums.
- Shortage of carbon based fuels will require development of new power generating systems that are not carbon based.
- Increased demand for renewable/sustainable energy.
- Increased requirements for environmental clean-up and remediation technologies.

Socio-cultural trends – changes in society provide opportunities, but lack of interest and inadequate levels of science education is a threat

- Increased urbanisation will lead to 57% of the world's population living in urban areas. This will have negative impacts on the availability of stable supplies of water, particularly for agricultural purposes, and will put pressure on the availability of agricultural land. Today, already 21 countries with a combined population of about 600 million are either cropland or freshwater scarce. Worldwide the roughly 1.2 billion persons to be added over the next 20 years and increased urbanisation will increase water and agricultural land shortages.
- There will be increased mobility of people in all countries.
- Growth of the middle class and of consumerism in emerging economies.
- Internationalisation of careers.
- Trends towards shorter career segments and several careers in a lifetime.
- Increased shift to internationalised tertiary education.
- Growth in international student numbers studying in Australia greater than for domestic students.
- Education trends in Australia and internationally indicating likely future shortages in STEM professionals and especially Physics specialists with a consequential negative impact on other professions such as engineering, medicine, biotechnology, manufacturing and others. This will also have a negative impact on the innovativeness of Australian business.
- Lower number of females choosing Physics classes in high school in Australia and as tertiary courses and careers will lead to a persistent gender imbalance in tertiary education, industry and business.

[13] Hajkowicz, S & Moody, J 2010, Our future world. An analysis of global trends, shocks and scenarios, CSIRO, Canberra.

- Children in Australia stay at home longer and Generation Y are not willing to move to study and/or work will lead to reduced exposure to external cultures, needs and new ideas and consequently will result in reduced innovativeness of business and industry in Australia.
- Decreased trust and respect of science in the community will not facilitate science education and investment in research and development.

Technology trends – hugely competitive global context, requiring high level skills, specific and focussed effort and resources from research through to commercialisation to exploit some of the numerous opportunities.

- The current slow technology adoption trends of 25 years for taking up major new technologies in the energy sector will be too slow to make significant changes to the energy grid architecture in most economies within the next decade. The greatest possibility for a relatively quick and inexpensive transition from fossil fuels in the next decade comes from better renewable generation sources (photovoltaic and wind) and improvements in battery technology. New technologies need to have the ability to store and use energy on demand from a combination of alternative energy sources. Hurdles to overcome relate to materials sciences and reducing cost of production and infrastructure
- Personalisation of products and services: A trend towards 'personal touch' and growth of the services sector based on innovation in technology that supports the services sector[14]. This includes the health care and services sector which requires improvements in biosensors for real-time monitoring of human health, robust information technology, ubiquitous DNA sequencing and DNA-specific medicine, and fully targeted drug delivery mechanisms.
- iWorld: Digital and natural world convergence and expansion of the internet[15] including tagging and networking of objects. This will lead to efficiencies of use within supply chains and logistics.
- Increase of non-military means of warfare, such as cyber, economic, resource, psychological, and information-based forms of conflict will require continued development of counter technologies and less focus on conventional military technology.
- Clean water technologies will emerge that have low energy requirements and infrastructure cost allowing the cost effective use and recycling of scarce water for industry, agriculture and domestic purposes. First movers to develop and deploy cheap energy-efficient clean-water technologies could gain huge economic and geopolitical advantages.
- Instrument manufacturers will build instruments and medical devices that increasingly do not need highly skilled professionals including physicists to maintain and monitor them for functioning (medical imaging, radiotherapy etc.),
- 'Greener' technology products will lead to decreased consumer product landfill,
- Super conductors and smarter materials for many applications.

R&D trends – increasingly global competition for talent and a shift of capability from west to east.

- R&D spending increases in the Asian nations is forecast to grow at a rate several times faster than that of advanced economies.
- Western economies will continue to struggle economically and will have limited success to entice industry and business to increase spending on R&D.
- Continued globalisation of research and development will lead to decentralising of large industry companies' R&D organisations and investment in and building of decentralised facilities in off-shore locations.
- The gap between the leading countries and emerging nations in research output and patent application is closing. The human resource skill gap in R&D between the US and India and China is expected to be closed within two decades. However, the gap in IP management and commercialisation and creativity management is expected to exist for longer.
- China's R&D position through investing in R&D will keep growing.

[14] Hajkowicz, S & Moody, J 2010, *Our future world. An analysis of global trends, shocks and scenarios*, CSIRO, Canberra.
[15] *Ibidem*

- Increased investment in the US and Europe in academic institutions is mirrored in emerging and transitional economies.
- Scientific collaborations between global leaders in technology and emerging nations will lead to increased competition between the collaborators later.
- "Greening" of national research and innovation strategies in OECD, BRIC and other countries will drive technical innovation in many industries.

Table 2 Global trends with impact on Australian Physics education, research and industry

The key technology trends summarised in Table 2 are expected to impact global economies and Australia's competitiveness in the global environment.

The technology trends identified by various learned organisations globally do not seem to reach much beyond the boundaries of current technology and what is probable or easily imaginable with current knowledge. Suggested technology interventions mostly rely on current research programs and require translation from applied physics research to engineering and technology development.

Due to the extremely long time lag between the formation of breakthrough ideas and technology development to concept and the commercial products - an example is the WiFi technology - it is likely that Australian physics will not deliver many or any research outputs with high economic or strategic impact within the next three decades unless there is a conscious and drastic step-up in research program innovativeness, management and commercialisation.

Research, development and commercialisation will need to look beyond the probable and likely trends and outcomes and explore solutions that currently appear technically and economically impossible.

School education in physics needs to be at a standard that is comparable to global technology leading countries to build capacity and develop the technology capability that enables the commercial exploitation of future research outputs.

Innovation trends

The OECD Science, Technology and Industry Scoreboard 2009[16] explored recent developments in matters relating to innovation, science, technology and globalisation. In this regard, it compares characteristics of OECD member and major non-member economies and provides information on the economic crisis and other global trends and challenges. Overall, the trends indicate that global economies are trying to innovate through higher standards of education and technology.

Major findings include:

- Historical data that show research and development (R&D) and venture capital are among the first expenditures to be cut during recessions in OECD countries. Preliminary data confirm this finding for the first half of 2009.
- Foreign direct investment (FDI) inflows to G7 countries dropped by 15% in 2008 owing to the economic crisis, a trend that was expected to continue in 2009. As foreign affiliates provide access to new technologies and generate knowledge spill-overs for domestic firms, lower inflows of FDI will reduce innovation capabilities in the host country.

[16] OECD Science, Technology and Industry Scoreboard 2009
http://www.oecd.org/dataoecd/25/59/44217002.pdf

- Patents in renewable energy and air pollution control are the most dynamic groups of environmental technologies.
- Inventive activities in nanotechnology have risen substantially since the end of the 1990s but the share of nanotechnology in total patenting remains just above 1% on average. Singapore is the country most specialised in nanotechnology.
- Business is an important source of funding for R&D performed in the higher education and government sectors, with an OECD-area average of 5.3% in 2006.
- High-technology goods have been among the most dynamic components of international trade over the last decade. In 2007 high- and medium-high-technology manufactures accounted for 23% and 39%, respectively, of total manufacturing trade.
- Information and communication technology (ICT) goods and services have been among the most dynamic components of international trade over the last decade. But the share of OECD countries in total world ICT trade decreased from 75% in 1997 to 52% in 2007 with the rapid rise in trade from non-OECD Asian economies.
- Patent data show a significant degree of internationalisation of research activities. On average, over 15% of the patents filed by an OECD country in 2004-06 under the Patent Co-operation Treaty concerned inventions made abroad.
- International co-authorship has also been growing rapidly. In 2007, 21.9% of scientific articles involved international co-authorship, a figure three times higher than in 1985.
- The US hosted the largest foreign doctoral population, with more than 92 000 students from abroad, followed by the United Kingdom (38 000) and France (28 000).
- Emerging countries are expanding their first-stage university system. Graduation rates in Russia (45%) are significantly above the EU average. In China the number of graduates has almost tripled since 2000, although the graduation rate (12%) is still low compared to the OECD average.
- Between 1998 and 2007, employment of tertiary-level graduates rose on average almost three times faster than total employment. Overall, 35% of persons employed in the OECD area had a tertiary-level degree in 2007.

Australia's track record in innovation

Australian physics is not an island in the Australian innovation landscape. Problems and weaknesses in the Australian innovation system that have a negative effect on other research disciplines in terms of the amount and speed of research and research output commercialisation will also affect physics negatively.

To take advantage of opportunities that are presented by current global trends, Australian physics needs to understand the strengths and weaknesses of the Australian innovation system and Australia's current competitive position in the international landscape.

According to the INSEAD global innovation index report 2011, Australia ranks 21st of 125 assessed countries, with a global innovation index of 49.9 out of 100[17]. The countries ranking number 1 to 5 are Switzerland, Sweden, Singapore, Hong Kong (SAR), and Finland respectively. On this global innovation index five input pillars capture elements of the national economy that enable innovative activities: (1) Institutions, (2) Human capital and research, (3) Infrastructure, (4) Market sophistication, and (5) Business sophistication. Two output pillars capture actual evidence of innovation outputs: (6) Scientific outputs and (7) Creative outputs. According to this study, Australian industry is fifth in the list of the top ten R&D importing countries.

[17] http://www.globalinnovationindex.org/gii/main/fullreport/index.html

According to the 2010 OECD Scientific and Industry Outlook[18], Australia's performance on innovation indicators shows a relatively unbalanced picture. In comparison to the OECD average, Australia performs above average in the number of scientific articles per million people and for HRST occupations as a percentage of total employment. However, this does not translate into impact in terms of triadic patents; research funds attracted from abroad and products new to market that are developed by Australian companies (Figure 3). Australia ranks reasonably among OECD countries in terms of small and medium enterprises collaborating in innovation with higher education and government institutions but for large firms Australia ranks towards the bottom of the group of OECD countries. This relatively unbalanced profile compares unfavourably with that of other small countries that are renowned for their innovation prowess, such as Finland. In 2008, in terms of scientific articles published per million people across all disciplines, Australia ranked behind Switzerland and before Canada, New Zealand, the United Kingdom and the USA. Australia's publication rate increased from 1998 to 2008 from around 900 per million people to over 1400. In comparison to Australia, Finland is at the top of the OECD country pool in five out of 13 innovation indicators (Figure 4), and in another four at least at the 8th percentile, including the number of scientific articles per million people. In terms of the number of researchers per thousand total employment, Finland is well ahead of Australia and also in terms of the proportion of firms that bring out new to the world products and of firms that collaborate with each other. These indicators, together with the high direct financial support by government and business and the high standing of Finland's school education record in OECD comparisons show a focused effort of the country on innovation as driver of economic wealth and on education and research and development as a primary contributor to innovation.

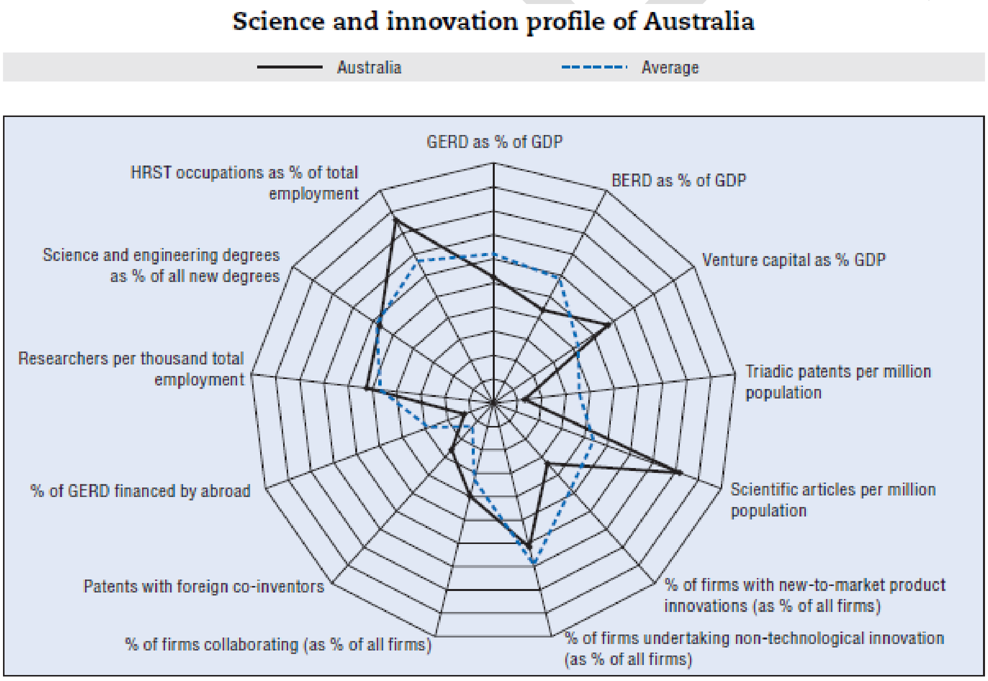

Figure 3 Australia's innovation record 2010

[18] OECD Science, Technology and Industry Outlook, 2010 Highlights. OECD 2010 http://www.oecd.org/dataoecd/38/13/46674411.pdf

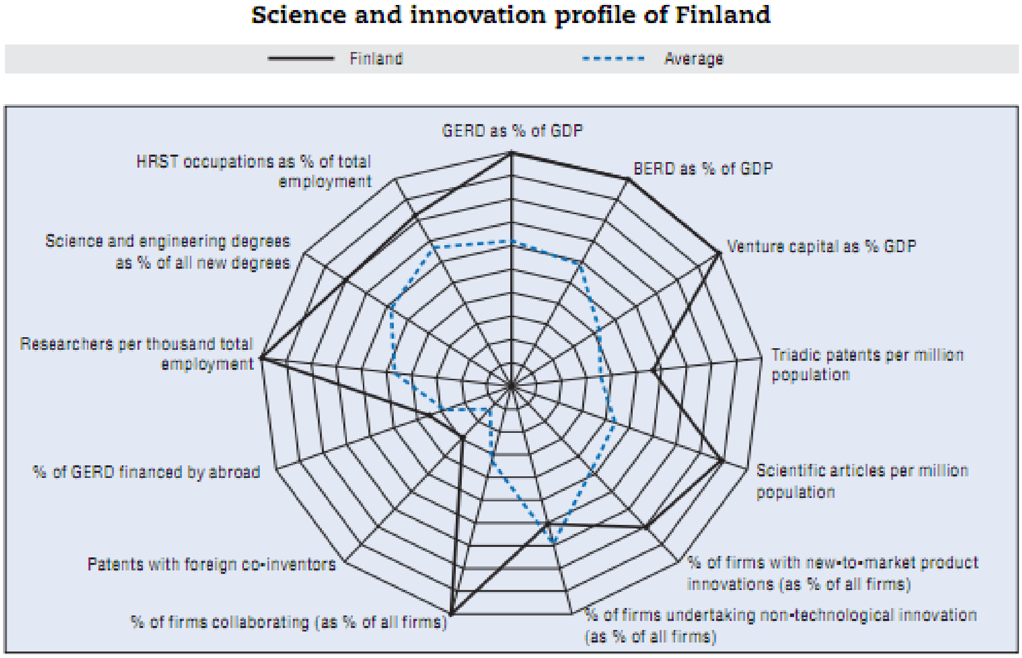

Figure 4 Finland's innovation record 2010

Australia has gaps of between 64% and 95% compared with the top five OECD countries in terms of all Intellectual Property (IP) indicators. This indicates that there is room for improvement, especially in the number of triadic patent families.

Australia falls into the top third of OECD countries for knowledge intensive market services, GDP per capita, and human development. It is in the middle third on labour productivity and global competitiveness, and in the bottom third on high and medium-to-high technology manufacturing, and high and medium-high tech manufacturing exports, exports in goods and services and environment performance.

In terms of the share of high and medium-high technology in manufacturing, a measure of global competitiveness in the world economy, Australia ranked 28th , towards the bottom of all OECD countries.[19]

Figure 5 shows that in Australia direct business expenditure o research and development (BERD) and indirect government funding of business through R&D, 2008 (as a percentage of GDP) is at the lower end of the OECD scale[20].

[19] Australian Innovation System Report 2010. Commonwealth of Australia 2010
[20] OECD Science, Technology and Industry Outlook, 2010 Highlights. OECD 2010 http://www.oecd.org/dataoecd/38/13/46674411.pdf

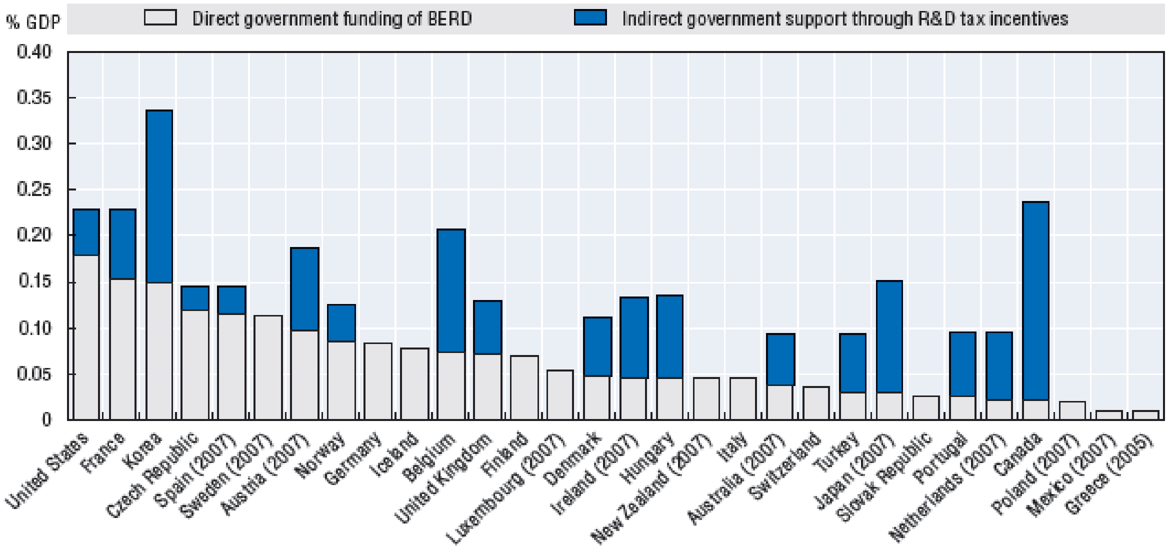

Figure 5 Government contributions to business expenditure on research and development in OECD countries

The issues identified by these publications have been of serious concern to Australian industry for some time [21] and calls for the transformation of Australia into the leading knowledge based democracy within the Asia Pacific region have been made to take advantage of global trends and make Australia competitive in technology and other industries. To achieve this requires strengthening the engagement between tertiary education providers and employers in order to develop the right skills and capabilities required for successful workforce participation in the future. Business also acknowledges the important role of the tertiary education sector in addressing the very widespread problem of limited numeracy, literacy and language skills. Physics can make a strong positive contribution to this much needed transformation.

Strategic direction of innovation in Australia

The strategies outlined by the Australian government in its Australian Innovation System Report 2010[22], in its innovation agenda[23], the national strategy for engagement with the sciences[24] and other reports indicate a desire and effort to address the current imbalances in Australia's innovation record.

Issues identified by the government's research skills strategy report[25] identified five major challenges for Australia's research workforce that need addressing in the coming decade:

- Meeting anticipated demand for research skills in the workforce;
- Strengthening the quality of supply through the research training system by improving the standard and relevance of research training programs;

[21] http://www.theaustralian.com.au/higher-education/higher-education-and-industry/story-e6frgcjx-1226085080915
[22] Australian Innovation System Report 2010. Commonwealth of Australia 2010
[23] Powering Ideas: An Innovation Agenda for the 21st Century, Commonwealth of Australia 2009
[24] Inspiring Australia: A national strategy for engagement with the sciences. Commonwealth of Australia 2010
[25] Research skills for an innovative future. A research force strategy to cover the decade to 2020 and beyond. Commonwealth of Australia 2011. http://www.innovation.gov.au/Research/ResearchWorkforceIssues/Documents/ResearchSkillsforanInnovativeFuture.pdf

- Enhancing the attractiveness of research careers;
- Facilitating research workforce mobility; and
- Increasing participation in the research workforce.

The stated opportunities in this report are outlined in Table 3.

Research Skills Strategy - Current and Future Opportunities
• Establishment of national research workforces planning processes • Increased flexibility within current scholarship programs to provide further financial incentives to attract students in demand areas • Expansion over time in the number of research training awards available to international students • Review of the RTS • Examination of the full cost of research training provision in Australian universities • Development of new models for research training focused on the professional deployment needs of graduates • Establishment and monitoring of research standards and quality benchmarks for research training • Establishment of a web-based communication platform for research career opportunities and support options • Review of the balance of fellowship support provided by the Government • Increase opportunities for early career researchers within the ARC Discovery Scheme • Incorporation in existing and future funding schemes of supported opportunities for inter-sectoral and international mobility • Further refinement of processes to remove impediments to individuals returning to the workforce after a career break • Investigation of metrics for measuring excellence in applied research and innovation • Removal of impediments for part-time candidature within research training support schemes • Development and promotion of family-friendly research workplaces • Implementation of an indigenous research workforce plan for the higher education sector

Table 3 Government research workforce strategies (Source: Research skills for an innovative Future. Commonwealth 2011)

Strategic direction of innovation in other countries

Amongst the OECD countries, similar strategic goals and recommendations on how to achieve them have emerged over the last few years. For example, the UK Scientific Century Report stated the following recommendations[26] (Table 4):

Recommendation 1: Put science and innovation at the heart of a strategy for long-term economic growth
- Create a new long-term framework for science and innovation committing to increased expenditure
- Outline spending plans over a fifteen year period (2011-2026)
- Prioritise investment in scientific capital – including infrastructure and skills
- Expand the R&D tax credit

Recommendation 2: Prioritise investment in excellent people
- Direct a greater proportion of Research Council funding to investigator-led research
- Increase the length and quality of UK PhD training
- Support transferable skills training for researchers
- Increase the number of postdoctoral fellowships

Recommendation 3: Strengthen Government's use of science
- Review strategic science spending by Government departments
- Expand the Small Business Research Initiative to support innovative procurement
- Provide Departmental Chief Scientific Advisers with greater resources Appoint a Chief Scientific Adviser to HM Treasury

Recommendation 4: Reinforce the UK's position as a hub for global science and innovation
- Extend the geographic reach of the UK Science and Innovation Network
- Increase support for mechanisms, such as the Science Bridges scheme, which link UK research groups with partners overseas
- Incentivise more of the world's best scientists to remain in, or relocate to, the UK
- Improve visa conditions for visiting scientists and researchers to the UK

Recommendation 5: Better align science and innovation with global challenges
- Create strong global challenge research programmes, led by RCUK, to align scientific, commercial and public interests
- Reform research funding and assessment to support and reward interdisciplinary research
- Use public and stakeholder dialogue to help identify and shape these challenges
- Ring fence departmental contributions to priority research areas

Recommendation 6: Revitalise science and mathematics education
- Provide incentives to recruit, retain and attract teachers back to science subjects
- Commit to increasing the numbers of primary teachers with science expertise
- Establish new expert groups to advise on the development of science and mathematics curricula and qualifications

Table 4 UK recommendation to increase the country's innovation and research competitiveness

Similarly, the US report "Rising above the gathering storm" in 2007 phrased a list of key priorities and recommendations which they based on the strategic goal of building and maintaining an attractive environment for energising and employing America's talent for a brighter economic future. As industry was seen as the major employment sector of the workforce, key criteria for industry to locate to and remain in the US were identified and the recommendations developed to maintain a healthy industry. The key requirements of multinational industry companies in their decision making processes for where to build their base were identified as:

[26] The Scientific Century: securing our future prosperity. Royal Society London 2010

- Cost of labour (professional and general workforce)
- Availability and cost of capital
- Availability and quality of research and innovation talent
- Availability of qualified workforce
- Taxation environment
- Indirect costs (litigation, employee benefits such as healthcare, pensions, vacations)
- Quality of research universities
- Convenience of transportation and communication (including language)
- Fraction of national research and development supported by government
- Legal-judicial system (business integrity, property rights, contract sanctity, patent protection)
- Current and potential growth of domestic market
- Attractiveness as a place to live for employees
- Effectiveness of national economic system

The report made the following recommendations:

Recommendation A: Increase America's talent pool by vastly improving K–12 science and mathematics education.

Recommendation B: Sustain and strengthen the nation's traditional commitment to long-term basic research that has the potential to be transformational to maintain the flow of new ideas that fuel the economy, provide security, and enhance the quality of life.

Recommendation C: Make the United States the most attractive setting in which to study and perform research so that we can develop, recruit, and retain the best and brightest students, scientists, and engineers from within the United States and throughout the world.

Recommendation D: Ensure that the United States is the premier place in the world to innovate; invest in downstream activities such as manufacturing and marketing; and create high-paying jobs based on innovation by such actions as modernizing the patent system, realigning tax policies to encourage innovation, and ensuring affordable broadband access.

It is clear that the recommendations of these two key countries, which are both collaborators in many research and commercial ventures with Australian research and development teams, start-up companies and mature industry, and also have large subsidiaries of key multinational companies in Australia, are similar to those of the Australian government.

It can also be seen, from a multitude of sources, that Australia's Asian neighbours are making substantial efforts to increase their competitiveness in innovation, business competitiveness and research capability. This means that the Australian physics community cannot afford to be left behind.

Impact of physics on innovation

According to an Ernst & Young business trend analysis in 2010[27] *"Disruptive Innovations in technology continue to have massive effects on business and society. We're now seeing emerging markets become hotbeds of innovation, especially in efforts to reach the growing middle class and low-income consumers around the globe."*

[27] http://www.ey.com/GL/en/Issues/Business-environment/Six-global-trends-shaping-the-business-world---Rapid-technology-innovation-creates-a-smart--mobile-world

Physics in many countries is seen as an enabler of innovation[28]. For example, in a 2010 study commissioned by the German equivalent of the Australian Institute of Physics and conducted by the Institute of German Economy, physics was defined as a driver of innovation in industry and business.

The 2010 study demonstrated the value of physicists to German industry[29]. Of the industry firms that employed physicists/mathematicians, 77% of these firms produced new products during the last two years, compared with only 47% of firms who did not employ any physicists/mathematicians (Figure 6).

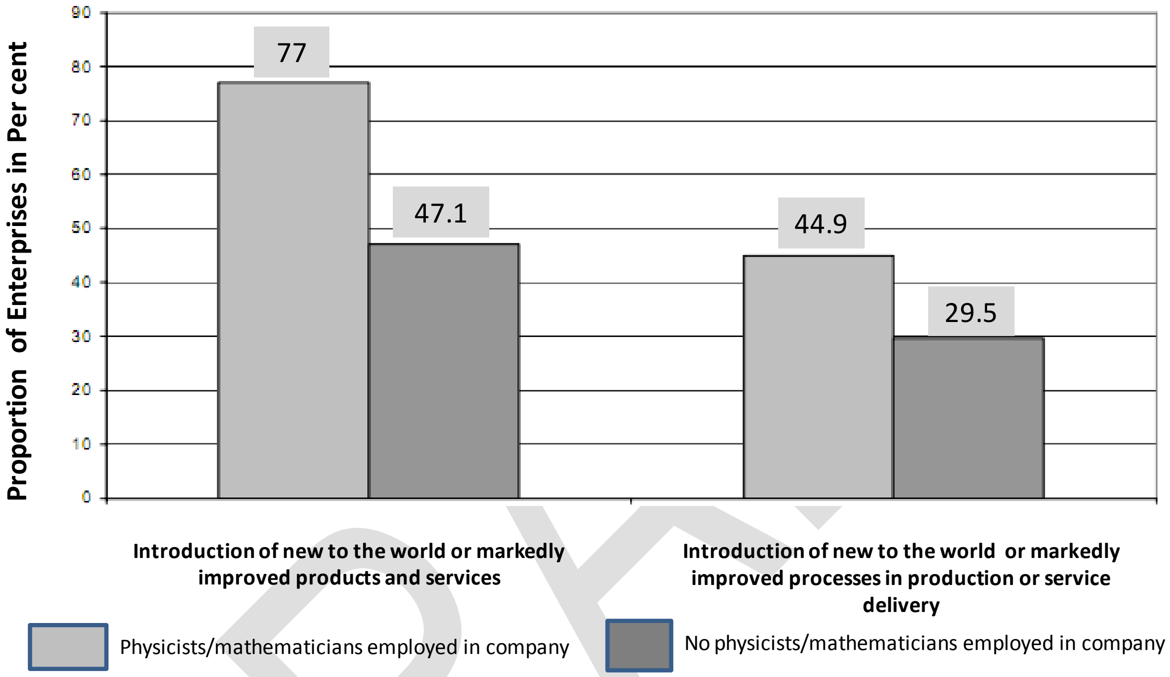

Figure 6 Employment of physicists/mathematicians in 2007 and innovation activity over the previous two years in German industry companies

Physicists were not only employed in large organisations but also by small (less than 50 employees) and medium sized businesses. Overall, the 10% of medium (50 to 250 employees) and large (more than 250 employees) German enterprises that employed physicists or mathematicians employed almost 74% of all industry employed physicists. Approximately 55% of all enterprises that employed physicists continuously conducted R&D activities and a further 26% occasionally.

Although it is not possible to determine a causal relationship between employing physicists and mathematicians and innovation success of businesses, it is clear that at least in Germany businesses who employed physicists in 2007 and 2008 valued them for their contribution to innovation activities - as they would have otherwise not employed them - and they benefited in terms of increased turnover from new products and services (Figure 7).

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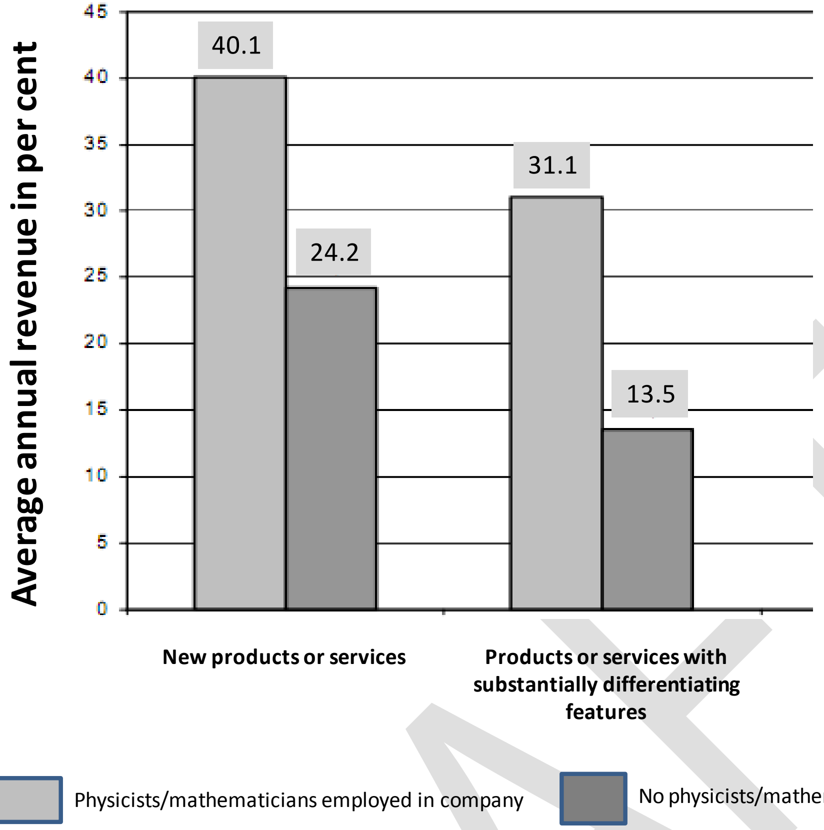
[28] http://www.dpg-physik.de/veroeffentlichung/broschueren/studien/arbeitsmarkt_2010.pdf

[29] Physikonkret: Physicer/innen im Beruf. 7. February 2010.



"Due to the highly independent and disaggregated nature of public sector research organisations, it is difficult for businesses to know what research is being undertaken."

Heather Ridout, Australian Industry Group in *The Australian* 2011

Figure 7 Employment of physicists and percentage of revenue from new products and services in German companies in 2008

A 2007 UK study on physics and the UK economy[30] analysed the impact in terms of value adding and employment in the UK in physics based industries. A physics based industry sector was defined as a sector where physics expertise or technology was critical to the sector's activities. The study showed that the turnover per employee between 2000 and 2005 in physics-based sectors was around £165 000 per annum – £93 000 more than the national average, where turnover per employee equated to around £72 000, also much greater than that of banking, finance and insurance, as well as construction. The economic activity of physics-based sectors, measured in terms of gross value added (GVA), stood at £70 billion in 2005 — making up 6.4% of the total UK economic activity. Productivity in physics-based sectors was also higher than the national average. In 2005, GVA per employee in physics-based sectors was approximately £69 000 — about 70% higher than in the UK as a whole. Although physics-based sectors are becoming more productive, they are generating less in turnover relative to the rest of the UK. The turnover generated by the physics sectors in 2005 amounted to £180 billion — 9% of the UK economy's total turnover.

For Australia no such statistics exist. However, assuming a similar relationship between employment of physicists and effectiveness of innovation, as described in the German study, it is likely that increasing the number of physicists in industry in Australia would lead to beneficial effects in terms of increased effectiveness of new product development.

[30] Physics and the UK economy. IOP study 2007. http://www.iop.org/publications/iop/2007/file_42709.pdf

Industry in Australia clearly sees benefits in collaborating and networking with the research community to enable access to ideas and expertise to solve ongoing challenges and create new products and services and become more competitive and profitable.[31]

The value of pure research and the broad social benefits that come from independent enquiry and pure research are not questioned by industry in Australia, and continued funding of fundamental research is widely supported. However, industry expresses hope that closer relationships with the research sector could better match applied research occurring in public sector research organisations with possibilities for development (and commercialisation) by bringing industry in early in the research process. To do that would require more flexibility in the IP transfer and partnership systems.

[31] http://www.theaustralian.com.au/higher-education/higher-education-and-industry/story-e6frgcjx-1226085080915

THE CURRENT GENERAL OPERATING ENVIRONMENT OF THE AUSTRALIAN PHYSICS COMMUNITY

To identify the constraints under which the various Australian stakeholder segments currently operate and their immediate and anticipated needs and requirements for the next decade, publicly available material on the operating environment of the physics stakeholder sectors was used to inform the interview process to identify the severity and currency of these constraints, needs and requirements.

Employment destinations for physicists

The current employment market for physicists is international. Due to English being globally the most commonly used language in research and technology, Australian physicists are well placed to take advantage of international employment opportunities.

The Australian Institute of Physics has, over the years, conducted employment reviews using job advertisements in newspapers, to ascertain where job opportunities for physicists appeared. The main driver of these reviews was Professor John Prescott of the University of Adelaide. In his paper "Jobs in Physics 2001: Much improved but uneven"[32], he shows a graph of the annual numbers of advertisements in larger city newspapers for jobs that require a physics background. It showed fluctuating demand of between just fewer than 400 to just fewer than 800 physicists a year for the years 1980 to 2000. This included research positions in academia funded through government funding agencies. By 2003 total positions advertised had dropped to less than 460 from 655 in 2001 (Table 5).

[32] http://www.physics.adelaide.edu.au/jobs/AIP_JobsReview01.html

			1984	**1988**	**1993**	**1999**	**2000**	**2001**	**2002**	**2003**
TOTAL positions (excluding Geophysics)			690	810	430	470	540	655	550	460
Commonwealth	CSIRO	Perm	6.4	5.4	5.4	4.3	2.9	4	4.4	1.3
		Temp	7.1	5.8	4.1	4.3	2.5	5.8	7.3	5.6
	Not CSIRO or defence	Perm	11.9	4.8	5.3	13.6	11.9	11.2	9.9	11.8
		Temp	2.8	1.4	2.2	2.8	3.7	4.1	4	7.4
	Defence		7.4	11.7	5.5	14.5	12.4	16.3	17.2	3.1
State			4.8	3.9	2.1	1.7	5.6	2.1	2.4	4.2
Medical, Hospital			2.8	4.3	4.2	1.9	2.2	5.8	7.8	5.5
University	Teaching	Perm	4.1	6.9	2.8	3.2	3.9	6.4	4.2	6.7
		Temp	4.5	7	6.5	2.6	3	3.7	4.9	4.4
	Research		11.3	11	22.7	27.2	28	23.2	21.5	23.2
	Technical and Other		4.5	6.6	1.6	1.3	1.7	0.8	1.5	3
Cooperative Research Centres (CRC)			-	-	12.6	3.2	2	1.5	0.4	1.3
Private Industry and Commerce	non sales		13	14	11.7	6.3	9	3.8	0.7	2.8
	Management and sales		2.6	2	1.4	2.2	2.5	0.8	1.4	0.1
School teaching, mostly independent (physics stipulated)			10.7	9.4	4.7	7.3	5.2	5.8	4.6	2.4
Overseas, various			6.1	5.8	7.2	3.9	3.5	4.7	7.7	7.7
TOTAL %			**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
Total positions Geophysics			**99**	**78**	**63**	**20**	**25**	**30**	**20**	**14**

Table 5 Job opportunities for physicists in the years 1984 to 2003

Over time, the recruitment sector has shifted considerably from advertising in newspapers to advertising on the internet, for example through "Seek", and to advertising jobs in journals and communication media that are specific to industries and professions.

A search on Seek at the end of April, 2011 found 253 jobs open that contained the term "Physics" in the job description or as a qualification requirement, and on May 12, 2011, 194 jobs. Many of these jobs were for physics teachers nationally and internationally; but also for medical physicists; for traders; for risk and financial analysts; in the oil, gas and mining sector nationally and internationally; in the IT and electronics industry; in fisheries and the wine industry; and for researchers in research institutions. Approximately one third were placed by the private sector, both in April (Table 6) and May[33].

Employment sector	Numbers	%
Education and Training	62	24.5
Science and Technology	61	24.1
ICT	27	10.6
Engineering	21	8.3
Government and Defence	17	6.7
Banking and Financial Services	12	4.7
Sales	10	4.0
Mining, Resources, Energy	8	3.2
Health and Medicine related	7	2.8
Market Analysis	2	0.8
Legal/IP	2	0.8
Health & Safety in Construction	2	0.8
Other categories	22	8.7

Table 6 Physics jobs on Seek on April 27, 2011

In overseas job markets, a job search on the Institute of Physics "Bright Recruits" job search website in the United Kingdom on April 27, 2011 there were over 300 international job openings for physicists in research, development and manufacturing, as well as in leadership positions (Table 7)[34].

[33] Prescott, J.R: Jobs in Physics in 2003: An unusual year. http://www.physics.adelaide.edu.au/jobs/AIP_JobsReview03.htmlhttp://www.physics.adelaide.edu.au/jobs/AIP_JobsReview03.html

[34] http://brightrecruits.com/jobs/ Accessed April 27, 2011

Physics Sub	Job ads
Accelerators and light sources	38
Astronomy and space	7
Biology and medical	20
Computer modelling and Mathematics	25
Defence and aerospace	3
Education and communication	10
Electronics and semiconductors	28
Energy and renewable	8
Engineering	41
Environment and Earth Science	4
Manufacturing and product development	7
Materials and characterisation	21
Nanotechnology	27
Nuclear and fusion	5
Optics and photonics	50
Software development	15
Total	**309**

Table 7 Physics jobs in “Bright Recruits” for March and April 2011

According to the Bright Recruits website, *“surveys by organizations such as the UK Higher Education Statistics Authority (HESA) and the American Institute of Physics (AIP) indicate that fewer than 15% of graduate physicists end up working in scientific research. AIP data show that 31% of recent Physics graduates working in the private sector are employed as engineers, while 32% have obtained posts outside science, technology, engineering or Mathematics.”*

On the same search day, the American Institute of Physics listed 167 research and development jobs for physicists. Of these, 94 were for academic positions, 23 for government and national labs, 30 for industry positions and 12 in other roles[35]. The American Physical Society (APS) Job Center website[36] also lists these same jobs.

The German industry job agency for engineering and technology (www.industriejob.de) listed 1548 open positions in industry on the same day that were open for physics graduates and experienced physics professionals[37]. Most of these jobs were in research and development functions. Many employers of physicists had several positions available, amongst them for example Robert Bosch with more than 150 jobs open for people with physics backgrounds, Siemens with 22 jobs, Carl Zeiss with 59, Daimler with 60 and BMW with 49 job openings.

[35] http://careers.Physicstoday.org/jobs/#/results/keywords=Physics&resultsPerPage=12/8,true Accessed April 27,2011
[36] http://careers.aps.org/jobs Accessed April 27, 2011
[37] http://www.stepstone.de/includes/listing/de/pb/industriejob/resultlist.cfm?keyword=Physik&newsearch=1 Accessed April 27, 2011

The fact that German industry companies in traditional industry sectors value physics qualifications, as indicated by the large number of available jobs for professionals with a physics background, and the same industry sectors in Australia, such as the automotive sector do not, may be a result of the low number of global industry companies with head offices and/or technology or R&D functions in Australia. However, it does not explain the low number of open positions for physicists in medium sized companies in Australia.

A report by the European Physical Society about numbers of graduate postgraduate physicists and other science talent educated and available for employment shows that employment destinations across the European market place from 1990 to 2000 was as follows:

- Industry and services for Graduates 70% and research and education 30%,
- Industry and services for postgraduates 60%, research and education 40%.

It is not clear what the employment destinations are for Australian graduates and postgraduates each year and it is even less clear over longer time periods. It is likely that more graduates and postgraduates in Australia are employed on an ongoing basis by the research sector. However, there are clearly positions available for physicists in many employment sectors, both nationally and internationally, but graduates need to be willing to move outside the capital cities and into overseas positions, especially if they want to work in industry.

The lack of visibility of physicists to industry, business and employment agencies in Australia could be addressed by the Australian Institute of Physics, in terms of building up information materials that provide information to industry and business on the value that physicists can add to industry and business innovation activities. The focus of physics graduates on trying to get hold of research positions is currently widely supported by the higher education and research sector, mainly because of the shortage of physics undergraduates in general which results in a shortage of highly capable candidates for postgraduate training and ultimately in long-term shortages of research careers candidates.

Professional representation of physicists in Australia

The professional body that represents the interests of individual Australian physicists is the Australian Institute of Physics (AIP). The body that represents the interests of physics as a science is the National Committee for Physics (NCP), a committee of the Australian Academy of Science. Of the 6,000 or more physicists or people with physics qualifications who are estimated to be employed in Australia, 1220 are currently individual members of the AIP. Membership is based on achievement criteria (Associate, Full membership and Fellow) with higher levels attracting higher membership fees. Associate membership is available to undergraduate students and full membership is open to physicists after graduation. There is no membership available to other individuals or entities interested in physics, such as school students, schools or industry companies. Reduced fees are available for individuals who are members of other physics sub-discipline membership organisations such as the Optical Society and others. The existing numbers of members represents only a minority proportion of physicists working in Australia.

The current membership base of the AIP represents a professional visibility of approximately one physicist per 25,000 people in Australia. In comparison, Germany has a membership of their equivalent organisation DPG of approximately 60,000, which represents one interested entity in physics (individual and/or organisation employing or representing physicists) per 1400 members of the general population. The American Institute of Physics has a membership of 125,000 and accepts not only individual physicists as members but also organisations, students and also represents related professional disciplines such as other scientists from other sub-discipline organisations and engineers. It represents and provides organisational support for 10 other physics based societies, thus bringing American physics under one umbrella. This represents one interested individual or entity per 2500 members of the general public. Furthermore, membership fees to the AIP are high compared to other international physics professional organisations, but this is probably only one of the contributing factors to low membership. The consequence of the low membership is low funds to run the AIP and deliver value to its members.

Australian physics community consultation and survey

Although secondary and desk top research provide valuable information, this information is generally not current but is critical to develop insightful interview questions that address key points relevant to the current experiences of the physics community.

Further input into the development of questions to the physics community was provided through the town hall meeting process at the 2010 Physics Congress in Melbourne.

Consultation, requirements identification and survey process

To identify the current positives, negatives, constraints and weaknesses in the general operating environment of the physics community, 65 in-depth interviews were conducted. The research method followed a slightly modified approach of Burchill and Hepner Brodie[38] that was developed for new product and service solution development. This approach is used in industry and business to rapidly determine the key customer requirements that need to be addressed to enable sustained competitive advantage in the market place, and has a strong track record as a tool for new product and service development. The process enables the identification of problems and constraints in the operating environment and of the requirements that must be met for the community to be functional, effective and competitive in the future.

The full list of interviewees is provided in Appendix 6 and the full report, that includes the detailed description of the interview and subsequent survey process is attached as Appendix 9.

The 65 people interviewed for this project included primary school students, high school students, teachers, undergraduate and higher degree students, researchers and employees across a variety of organisations that employ physicists (industry, business, government, universities, research institutes, CSIRO, DSTO, hospitals etc.) as well as self-employed physicists. Many interviewees had experience in more than one stakeholder sector and had more than one area of expertise (for example physics and engineering).

A map of the general physics community environment and a map of the needs areas were agreed by interviewees. Subsequently, from both maps and the requirements voiced during the town hall meetings at the 2010 Physics Congress, a list of operational requirements was developed that could be tracked against results and progress metrics. A list of the 39 most commonly voiced requirements was then widely distributed as a survey to the physics community, for example through the membership lists of the AIP, APESMA, IEEE Australia and the Australasian College of Physical Scientists and Engineers in Medicine (ACPSE), and through targeted emails to all previously interviewed people, Physics Departments within the university system, CSIRO, ANSTO, DSTO and other organisation, with the request to pass it on to their networks of industry specific associations and individuals. In total, the survey was accessible to more than 3000 people.

The survey results were then ranked using an opportunity index that took into consideration both the importance of each requirement and how well each requirement was perceived to have been already met. The list of requirements ranked by opportunity index is provided in Appendix 9.

A high opportunity index of 7 - 10 generally means that the requirement is both important and currently not sufficiently met. Addressing these requirements through appropriate solutions will generally lead to high satisfaction throughout the community and will generally address shortcomings that are severe constraints. An opportunity index of 5 - 7 can indicate that the requirement is important but is already being met to some degree. There may be opportunities to do better with such middle ranked requirements. To focus on or

[38] Burchill, G. and Hepner Brodie, C. Voices into Choices. Center for Quality of Management, (Cambridge, Massachusetts), Joiner Associates 1997

prioritise requirements with an opportunity index below 5 is generally not a good allocation of resources (subject to better options being identified) because they are regarded as being of lower importance.

The current operating environment map

The current operating environment map of the physics community shows that there are many interdependencies between the sectors of the physics community in terms of identified issues and constraints.

The Physics education sector's two 'legs' - school and higher education - are highly interdependent in terms of the competency of science and physics teachers affecting both the attitude and capabilities of school students which in turn affects the number and capability of each year's new cohort of tertiary physics students.

The tertiary education sector on the other hand influences the attitude of physics students towards careers other than research, including teaching careers, as well as influencing the quality of teacher education. Shortcomings in either of these components of the education system are perceived to have a severe detrimental domino effect on the capabilities of the other sectors of the physics community, the general science literacy of the public and on Australia's economy. Constraints in these two sectors are seen as equivalent to turning off a tap that has the potential to irrigate fertile fields, but instead delivers a mere trickle of muddy water.

Interviewees generally agreed that the research sector (government owned and university research providers) had the highest influence on the technology supply chain in terms of the quality and impact of their main outputs; knowledge, graduates, postgraduates trained in research processes and intellectual property that can be used by industry and business.

It was acknowledged by the majority of interviewees in all sectors, including industry and government, that funding of fundamental and basic research is essential as an indicator of an 'intelligent' and 'clever' country with scientists that are able to compete on the world stage. That breakthroughs in knowledge only occasionally lead to commercialized technology applications is not seen as an issue or something that should impact on the value and merit of undertaking and funding fundamental research.

Shortcomings and constraints in the university sector in terms of available numbers of high quality and capable graduates and trained researchers are believed to have a detrimental downstream effect on the ability of the other major Australian research providers such as CSIRO, DSTO and ANSTO to attract high quality physicists and deliver their mission based research outputs.

There are some additional difficult issues that are perceived to hold the physics community back. One of these is the conservative approach to many aspects of research, education and industry interaction, especially of the higher education and research sector, and within this sector the 'sandstone universities' are considered to be especially problematic.

The perceived remoteness of the higher education and research sector from the rest of the physics community was believed to be mirrored by similarly conservative processes of the major funding agencies.

The impact of this doubly applied conservatism was seen as stifling the emergence and funding of the "large ideas" that are needed to keep Australia at the forefront of research in the global context, and also for the continued competitiveness of Australian industry companies that need inventions to emerge from Australian higher education and research.

The key issues and constraints of the map, as identified by the physics community, are summarised in the following sections.

- **The academic research sector is currently inwardly focused.**
    - The research environment is perceived as unexciting and insular.
    - Opportunities and talent are lost due to conservative thinking and actions.
    - The research community has a negative attitude towards industry interaction.
    - There are gaps and overlaps between Physics and Engineering which are managed in different ways by different universities.

> *"From my experience, academia is looking towards industry engaging them, and industry will never do that; it's academia who needs to engage industry"*
>
> Industry representative

- **Job security is a major problem in retaining talented researchers in academia and in research institutions**
    - High calibre Physics talent is emerging but there are limited opportunities for advancement in Australia
    - There is no long-term job security in research for most people

- **Employment opportunities exist for graduates outside academia, but are difficult to match up.**
    - There are employment opportunities for Physics graduates with sound theoretical knowledge and practical skills
    - The quality of interaction between potential employers and academia limits identification of job opportunities.

- **Lack of understanding of the contribution of physics to society -- specialist teaching is limiting interest in physics in schools.**
    - The desire for a Physics career is shaped early, and often by positive school-age experiences
    - The quality of high school Physics teaching is limited by lack of specialist Physics teachers
    - Physics' contribution to modern society is fundamental but not well recognised

> *"Our company believes that the graduates, for their education, need to move around; getting people out of the cafés in Carlton – that is an issue for us."*
>
> Multinational industry representative

- **Administrative and funding processes are negatively impinging on research efficiency and productivity.**
    - Academics experience an increasing burden of administrative and managerial activities
    - The research funding system does not support cross-disciplinary research
    - The funding system does not fully cover the cost of research projects

> *"The grants* are so long and difficult to write; that's something which makes me not so excited about trying to become an academic. *My supervisor spends a third of the year, each year writing grants, that doesn't sound like heaps of fun. I'd rather spend my time doing research"*
>
> PhD student

- **Physics is a major contributor to the global research competitiveness of Australian research providers -- some of the capabilities are world class.**

> *"We have very tough selection criteria for strategic long term relationships with universities, for example excellence in research; good international reputation; high degree of interdisciplinary teams but a proximity to our locations as well; then it has to be a top university for our talent acquisitions"*
>
> Multinational industry representative

- **Translation of research outputs into technology through commercialisation is a major problem area.**

The physics community needs map

The physics community needs map (Appendix 9) mirrors, to a large degree, the constraints identified in the operating environment map.

At the top of the list of needs is the need for at least maintaining, but better still, increasing the current state of excellence, not only in research but also at a systemic level throughout the physics community and all its processes, from school education through to commercialisation of research results and reaching the full potential of available talent.

Remaining at the highest level of excellence in research is seen as being of utmost importance. Only the highest level of excellence in research will attract both national and international funding by government funding agencies and industry over the next decade and beyond. It was made clear by industry interviewees that industry has access to research talent and infrastructure globally and that they source the best expertise available, regardless of location.

An obstacle to reaching this level of excellence is seen to be a perceived decline in the quality of education of school students in physics. This was primarily attributed to the lack of qualified physics teachers and a physics curriculum that is perceived as being uninspiring and irrelevant, which in turn limits the pool of high quality university entrants.

A further obstacle to reaching systemic excellence is seen in the potential disruption of a predictable level of funding for research, as wide fluctuations in funding that would most likely result in the depletion of the Australian physics talent pool through migration into overseas research institutions.

There was a general consensus throughout the physics community that the highest payoffs in terms of new knowledge and in new technologies will come from cross-disciplinary research programs and bringing in of talent from outside conventional sources. However, there is also support for implementing changes to funding agency processes to facilitate high risk, high payoff ideas being pursued and for better mentoring of young talent in all research organisations (not only universities).

There is strong awareness in the physics community that the career structures within the higher education and the research sectors as a whole are quite rigid, prescribing specific steps. The current attitude towards preference of research only careers without easy exit and entry ramps to and from industry or to and from family commitment based career breaks, has led to funding agencies and research organisations implementing Research Opportunity and Performance Evidence (ROPE) guidelines to prevent researcher disadvantage on the basis of gender, family commitments and industry activity.

The physics community is generally aware that the gender balance is severely skewed towards men in all sectors.

It is clear that the lack of transparent and equitable metrics and reward systems, for example those that measure excellence based on publications, is seen as worth addressing in the context of maintaining excellence. The currently high focus on predominantly publication related metrics as the basis for performance assessment in the higher education and the research sector in general is not regarded as balanced in today's research and industry and business environment.

There is also support for utilising external new ideas and talent to invigorate the physics sub-disciplines and there is support for facilitating temporary entrepreneurial engagements without prejudicing research career progression.

The physics community is generally aware that the siloed approach of the sub-disciplines is detrimental to portraying a common and inspiring image of physics and also for fostering collaborative and cross-disciplinary research, even amongst the physics sub-disciplines.

The requirements relating to investing into mechanisms for better engagement of the higher education and research system with the school sector found high support throughout all sectors of the physics community.

A unified image of physics, the development of information materials for undergraduates about potential professional directions they could take instead of only promoting research careers is regarded as providing opportunities for young physicists to broaden their view towards other employment opportunities outside the research sector. Senior academics will need to play a major role in this endeavour.

Improved interactions between the higher education and research sectors and industry will provide additional benefits to the higher education sector in terms of developing up to date understanding of industry and business needs in terms of skills and talent.

The major areas of need were identified as:

- **Focused consolidation is needed to maintain long-term international excellence.**
    - The culture of excellence in Physics must be maintained
    - The tertiary sector needs to be rationalised to maintain delivery of high quality education and research training.

- **The physics research community needs to implement more flexible career structures and paths.**
  - There is need to address the loss of female talent, especially in the early research career years and support their career progression
  - There is a need to support temporary entrepreneurial engagements without prejudicing research career progression

- **The physics research community needs to embrace applied research and commercial relationships.**
  - The Physics community needs to ascribe greater value to applied Physics.
  - Closer and longer-term relationships between the Physics community and industry need to be developed in targeted areas.

- **Physics needs to be invigorated by tackling big problems using more courageous and adventurous approaches.**
  - Physics needs to be invigorated by tackling big problems using more adventurous approaches
  - Research organisations need to implement mechanisms that make working across disciplines easier.

- **The higher education and research system needs to invest in engagement with the school sector at all levels to inspire interest in physics.**

> *"At age 9 or 10 I worked out the things that I enjoyed doing, which was messing about, trying to understand how things worked, whether that was models or rockets, or electronic bits and pieces. Because that actually was called physics, then I realised that that was what I wanted to do"*
>
> University professor

- **Undergraduate physics needs to be made more attractive by giving it a higher vocational emphasis.**
  - For graduate employability there needs to be a better match between course content and employer requirements
  - The education of graduates needs to include more practical experience to increase employability

- **The physics community needs to explore the relevance of its performance metrics.**

Consultation and survey conclusions

The survey of the wider physics community on a number of requirements, mirrored the issues and constraints established in the analysis of the operating environment. However, it was agreed that the physics community needs to maintain excellence, re-energize through new approaches and engage more broadly with society.

A clear outcome from the interview process, the development of the maps, and the survey process on the requirements, is the identification of the relatively rigid boundaries between the individual stakeholder sectors, especially between the higher education and research sector, and its 'customer' stakeholder segments. Although there is generally good will by all parties, the hurdles to closer interactions are perceived to be difficult to overcome without external enforcement of rules and a broader metric set.

Many of the obstacles to effective and efficient use of research and education funding that the physics community believes will affect their future prosperity and viability, are seen to be of lower importance by the portion of the physics community that is non-research focused. Similarly, a further indicator for maintaining the current status quo appears to be reluctance to implement any changes to systems and processes that could have an effect on the current gender balance in physics.

The relatively low importance given by the research sector (especially academia) to the interaction between the industry/business sector and the research sector will make it difficult to set up fruitful interactions. A potentially useful step would be to agree on expectations of both of these physics stakeholder sectors.

The international comparisons of school student performance show that Australian school students are currently not below international average, but a downwards trend is already evident. The focus on the school curriculum by survey respondents as their number one opportunity for change identifies a pending and potentially severe supply issue for physics. Other bottle necks, such, as insufficient physics teacher training and a lack of a clearly understandable 'picture' of physics as an attractive option in the eyes of the public, of school students and their parents as well as employers also exist. The curriculum is only one potential point where positive changes could be made. Indeed, focusing only on the curriculum would provide a threat to physics in terms of taking its eye off other things that need to be addressed in parallel.

OUTCOMES OF SECONDARY RESEARCH ON PHYSICS COMMUNITY STAKEHOLDER SECTORS

The following sections of this report outline the findings of secondary and desktop research that was conducted to build a picture of the physics environment and to inform the questions to ask in the general physics operating environment interview process. It outlines how the main stakeholder sectors of the physics community perform in the context of the identified global trends and challenges.

The school education sector - primary and secondary education providers

Key points

- The performance of Australian school students is currently above the international OECD average. However, the performance is sliding and is substantially lower than that of the major economies in the Asia Pacific region.
- Physics is the discipline in which students perform poorest.
- Nearly 43% of senior school physics teachers lack a physics major, and one in four has not studied the subject beyond first-year.
- Geology teachers have the lowest levels of discipline-specific qualifications. More than half of these teachers have not studied any geology at a tertiary level.
- Compared to their older colleagues, younger science teachers are more likely to have studied biology and less likely to have studied physics.
- These findings may go a long way to explain the lower performances of the Year 4 and Year 8 students in the TIMSS 2007 and the PISA 2006 studies in the subjects physics and earth sciences, and the poorer performance of students in remote areas where younger and less qualified teachers are employed.
- There is a clear gender imbalance evident, with girls performing less well in physics and mathematics. This imbalance is already evident in primary school.
- The critical point of intervention to halt the slide in interest in science subjects in school and especially in physics and mathematics as well as the gender imbalance in these sciences is in the primary school and early high school years
- Teachers play a critical role in raising interest and a positive attitude to these subjects in the early school years but they currently have insufficient training in the subject matters of physics and mathematics.
- The existing gender imbalance in year 8 in terms of lower confidence and subject matter competence in girls will continue to translate into girls not taking up tertiary studies in physics and mathematics and to girls preferentially pursuing careers with currently lower demands on competency in these fields of science (including primary and secondary school teaching).
- The current low level of science qualification of primary school teachers and their “feeling of relative un-preparedness” to teach physics related topics will continue to set the scene for many years to come if a serious intervention program is not initiated.
- To leave the issue of teacher qualification in science, especially physics and mathematics unaddressed, will have severe negative knock-on effects on all the other sectors of the physics community, on other disciplines, industry and business, and on the Australian economy in general.
- In the context of this plan, mechanisms for improvement of physics teachers’ initial education and training as well as the improvement of insufficiently effective in-service physics teachers will need to be addressed urgently.

- The power to effect required changes is predominantly in the hands of the federal and state governments.

The most recent source of school education benchmark data is in the year 2007. In 2007 there were over 3.4 million full-time school students and over 240 thousand full-time equivalent (FTE) teaching staff in Australia. There were 9,581 schools, of which 6,853 (71.5%) were government schools and 2,728 (28.5%) were non-government schools. Of all non-special schools 70.8% were primary only, 16.2% were secondary only, and 13.0% were combined primary/secondary schools.

In 2010, student to teaching staff ratios for government primary and secondary schools were 15.4 and 12.3, compared with 16.5 and 11.7 for non-government schools. Generally student to teaching staff ratios have decreased across all affiliations, states and school levels in the last ten years[39]. The main resource issues hindering instruction in 40% of schools in Australia was identified as 'lack of qualified teachers'[40].

Primary and secondary education is administered by state governments in Australia which means that there are almost as many different curricula and practices as there are states and territories. There is a recent development in the attempts to define a national curriculum in some subjects at the secondary school level which is intended to create a more uniform treatment of these courses. It is also expected that there will be a common baseline for all matriculating students facilitating greater mobility between states at both the secondary and tertiary levels.

Recent reforms in the pre-school area oblige staff to incorporate some training into children's daily life which opens up opportunities to introduce discovery to this cohort. However, at present this is a very uncoordinated program for instruction.

Comparison to international benchmarks

There are two internationally benchmarked school student performance assessment vehicles used to compare student performance, the Trends in International Mathematics and Science Study (TIMSS) which is repeated every 5 years, and the Program for International Student Assessment (PISA). PISA conducts a comparative assessment of 15 year olds across the breadth of Reading, Mathematics and Science subjects, whilst TIMSS focuses on assessing performance in mathematics, physical, life and earth science at the Year 4 and Year 8 levels, i.e. at age 10 and age 14. TIMSS has a more explicit curriculum focus than PISA, and provides data on subjects that are covered by most countries.

TIMSS 2007 results

According to the TIMSS Study 2007, the performance of Australian Year 4 students in science has remained relatively unchanged since 1995. However, the score for Year 8 science has declined by 12 score points since 2003. Indigenous Year 4 students scored on average 90 score points lower than their non-indigenous counterparts and this gap has increased. In Australia, boys generally outperformed girls in both mathematics and science at each year level, in contrast to the international trend for girls to outperform boys[41,42,43].

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[39] ref http://www.abs.gov.au/ausstats/abs@.nsf/lookup/4221.0Main+Features62010?OpenDocument
[40] http://www.oecd.org/document/55/0,3746,en_2649_37455_46349815_1_1_1_37455,00.html
[41] TIMSS 2007 Taking a closer look at Mathematics and science in Australia http://www.acer.edu.au/documents/TIMSS_2007-ExecutiveSummary.pdf
[42] TIMSS 2007: Taking a closer look at Mathematics and science in Australia. http://www.acer.edu.au/documents/TIMSS_2007-AustraliaFullReport.pdf

TIMMS 2007 assessment of performance in physical sciences required Year 4 students to answer questions relating to:

- Classification and properties of matter
- Energy sources, heat, and temperature
- Light and sound
- Electricity and magnetism
- Forces and motion

Year 8 students were required to demonstrate a more advanced level of understanding of:

- Physical states and changes in matter
- Energy transformations, heat, and temperature
- Light
- Sound
- Electricity and magnetism

Students needed not only to be familiar with the subject content but were also assessed on how they used the content within the three cognitive domains of knowing, applying and reasoning.

Although Australian Year 4 students ranked above the world mean, they ranked well below Singapore, Chinese Taipei, Hong Kong SAR, Japan and the Republic of Korea, countries that have emerged as the economic power houses of the Asia Pacific region, and also below the Russian Federation, England and the USA. A number of European countries such as Germany, Sweden, The Netherlands, Italy and Hungary have similar performance to Australia. Similarly, Australian Year 8 students ranked above the international mean (just) but well below its Asian neighbours, the Russian Federation and England.

[43] Highlights of TIMSS 2007 from an Australian perspective http://www.acer.edu.au/documents/TIMSS_2007-AustraliaHighlights.pdf

	Year 4		Year 8	
Country	Advanced and high benchmark	Low and less than low benchmark	Advanced and high benchmark	Low and less than low benchmark
Singapore	68	12	61	20
Chinese Taipei	55	14	60	17
Japan	51	14	55	14
Korea Rep. of	n/a	n/a	54	15
England	44	19	48	21
Hong Kong SAR	55	12	45	23
Russian Federation	49	18	41	24
USA	47	22	38	29
Australia	**41**	**24**	**33**	**30**
Australia, boys	**42**	**23**	**39**	**27**
Australia, girls	**38**	**23**	**28**	**33**
Australia, indigenous			**14**	**68**
International Median	34	26	17	51

Table 8 Percentages of students reaching international benchmarks in year 4 and Year 8 Science compared to a number of countries that ranked higher than Australia

There was no gender difference between boys and girls in performance in the Year 4 science subjects. However, in the Year 8 subjects girls scored 19 points lower than boys, and Australia ranked ahead of only four other countries that had a larger proportion of girls with lower performance than boys. These were Tunisia, El Salvador, Ghana and Columbia. In the top scoring Asian countries there was no significant gender difference in performance. The comparison between the TIMSS 1995 and 2007 assessments showed no change in the gender imbalance over the years.

In Year 8, boys performed at a level similar to students of the same age in the USA, but less than a third of girls were at an advanced or high performance standard and one third of girls had not met or only just met the low performance standard (Table 8).

When comparing the performance of children in both age groups in the content domains, in Year 4 it can be seen that although Australia ranks above the international median in all three domains, the scores for the three domains are lowest for the physical sciences; this contrasts with the main top performing countries in which performance in the physical sciences is generally higher than in the other domains (Table 9).

	Average scale scores for science content domains for year 4		
Country	Earth Sciences	Life Sciences	Physical Sciences
Singapore	554	582	585
Chinese Taipei	553	541	559
Japan	529	530	564
England	538	542	543
Hong Kong SAR	560	532	558
Russian Federation	536	539	547
USA	533	540	534
Australia	**534**	**528**	**522**
International Median	500	500	500

Table 9 Average science scores for the science content domains for year 4.

In the three science cognitive domains, Australian Year 4 students showed a lower overall performance in all three cognitive domains than its nearest similar performing country, the USA (Table 10).

	Average scale scores for the cognitive domains for science for year 4		
Country	Knowing	Applying	Reasoning
Singapore	587	579	568
Chinese Taipei	536	556	571
Japan	528	542	567
England	543	536	537
Hong Kong SAR	546	549	561
Russian Federation	542	546	542
USA	541	533	535
Australia	**529**	**523**	**530**
International Median	500	500	500

Table 10 Average scale scores for the three cognitive domains for year 4

In Year 8 Physics, Australian students, with a score of 508 points, performed at a level that is not statistically different to the international average of 500 points. The USA, Armenia, Lithuania and Scotland are also in this performance band. Only 11 countries (Chinese Taipei, The Czech Republic, England, Hong Kong, Hungary, Japan, Korea, the Russian Federation, Singapore, Slovenia and Sweden, scored above the 500 point average. The remaining 33 countries performed below average in physics.

In Year 8, performance in both chemistry and physics in Australia was just above the international average. The highest performing countries, Singapore and Korea, scored 67 and 63 points higher in physics than Australia (Table 11).

	Average scale scores for the four science subjects in Year 8			
Country	Chemistry	Earth Science	Biology	Physics
Singapore	560	541	564	575
Chinese Taipei	573	575	549	554
Japan	551	533	553	558
Korea Rep. of	536	538	548	571
England	534	529	541	545
Hong Kong SAR	517	542	527	528
Russian Federation	535	525	525	519
USA	510	525	530	503
Australia	**505**	**519**	**518**	**508**
Australia boys	**512**	**532**	**522**	**522**
Australia girls	**497**	**505**	**515**	**492**
International Median	500	500	500	500

Table 11 Average scale scores for the four science subjects in year 8

	Average scale scores for the cognitive domains for science for year 8		
Country	Knowing	Applying	Reasoning
Singapore	554	567	564
Chinese Taipei	565	560	541
Japan	534	555	560
England	530	538	547
Hong Kong SAR	532	522	533
Korea	543	547	558
Russian Federation	534	527	520
USA	512	516	529
Australia	**501**	**510**	**530**
Australia boys	**512**	**519**	**535**
Australia girls	**488**	**501**	**526**
International Median	500	500	500

Table 12 Average scale scores for the three cognitive domains for science in year 8

In the three cognitive domains, performance had deteriorated compared to Year 4, with a comparative weakness in the knowing domain in Year 8 (Table 12). The gender difference between boys and girls was not significant in biology for reasoning.

The study showed that a positive attitude towards mathematics and science is correlated to a higher achievement in these subjects. In Australia, the positive attitude index of Year 8 students towards mathematics has decreased since 1995.

Regardless of how much students like or value mathematics and science, students' confidence in their ability to learn mathematics and science appears to be based, at least to some extent, on their previous experience with learning these subjects. This experience could be influenced by the perceived difficulty of the subject, the confidence with which the teacher presents a subject and also the individual student's own learning ability.

Amongst Australian students, as well as internationally, mathematics and science achievement was highest amongst students with high levels of subject self-confidence, next highest amongst students with medium levels, and lowest amongst those reporting low levels of self-confidence.

At Year 4, boys already had higher self confidence in learning mathematics and science than girls and this gap in confidence appears to have widened by Year 8. The report suggests, after more in-depth analysis of the data, that the gender difference in mathematics performance in Australia can be explained by differences in self confidence in learning mathematics and science subjects.

Another aspect of data reported in TIMSS is that the students attitudes towards mathematics and science declines between Year 4 and Year 8 both in an absolute sense, but even more dramatically relative to the international average (Tables 13 and 14). The positive affect towards mathematics/science (M/S) is measured on the basis of:

- I enjoy learning M/S;
- M/S is boring (reverse scored);
- I like M/S.

	High Positive Affect to Mathematics		Medium Positive Affect to Mathematics		Low Positive Affect to Mathematics	
	Year 4	Year 8	Year 4	Year 8	Year 4	Year 8
Australia	66	34	16	27	18	39
International Average	72	54	14	21	14	26

Table 13 Positive attitude towards Mathematics declining from year 4 to 8

	High Positive Affect to Science		Medium Positive Affect to Science		Low Positive Affect to Science	
	Year 4	Year 8	Year 4	Year 8	Year 4	Year 8
Australia	78	47	11	22	11	31
International Average	77	65	13	19	11	16

Table 14 Positive attitude towards Science declining from year 4 to 8

Equally of concern is the value or relevance that the students place on science as part of their education and life. This is only reported for Year 8 students, and while it is close to the international average for mathematics, it is well below the international average for science (Tables 15 and 16). This measure is based on the following responses:

- I think learning M/S will help me in my daily life;
- I need M/S to learn other school subjects;
- I need to do well in M/S to get into the university of my choice; and
- I need to do well in M/S to get the job I want.

	High Student Valuing Mathematics	Medium Student Valuing Mathematics	Low Student Valuing Mathematics
Australia	75	19	6
International Average	78	17	5

Table 15 Proportion of Year 8 students valuing Mathematics

	High Student Valuing Science	Medium Student Valuing Science	Low Student Valuing Science
Australia	42	30	28
International Average	66	23	11

Table 16 Proportion of Year 8 students valuing Science

Valuing science and, to a lesser extent, mathematics is a key issue in the declining interest in science. It is critical to determine whether this is a feature of the curriculum or the background training of the teachers. Given the data outlined above concerning the lack of highly discipline qualified teachers, it is unlikely that the context of science and its importance in life will be portrayed in the most attractive and meaningful manner to potential future scientists.

Mathematics as an enabling science for physics

In the TIMSS 2007 study, in mathematics at Year 4 Australia's 10 year olds were above the international average and there was no statistical difference between boys and girls, although boys' performance was slightly higher. At Year 8, Australia's 14 year olds performed at the world average. The gender difference at that age, where girls performed at a lower level, was statistically significant. This is in contrast to the international average for that age, where girls outperform boys at statistically significant levels.

The main participating Asian countries, the Russian Federation, England and the United States performed at higher levels than Australia at both age assessment points. The most striking difference though, is in the level at which international performance benchmarks are achieved in Australia's neighbours, the economically powerful Asian economies (Table 17).

	Year 4		Year 8	
Country	Advanced and high benchmark	Low and less than low benchmark	Advanced and high benchmark	Low and less than low benchmark
Singapore	74	8	70	12
Hong Kong SAR	81	3	64	15
Chinese Taipei	66	8	71	14
Japan	61	11	61	13
Korea Rep. of	n/a	n/a	71	10
Australia	**35**	**29**	**24**	**39**
Australia, indigenous			**7.3**	**67**[44]
International Median	26	33	15	54

Table 17 Percentages of Australian students reaching international benchmarks in Year 4 and Year 8 Mathematics, in comparison with the major Asian neighbours and the international average.

PISA results

	On the overall reading scale	On the reading sub-scales					On the mathematics scale	On the science scale
		Access and retrieve	Integrate and interpret	Reflect and evaluate	Continuous texts	Non-continuous texts		
OECD average	493	495	493	494	494	493	496	501
Shanghai - China	556	549	558	557	564	539	600	575
Korea	539	549	541	542	538	542	546	538
Finland	536	532	538	536	535	535	541	554
Hong Kong China	533	530	530	540	538	522	555	549
Singapore	526	526	525	529	522	539	562	542
Canada	524	517	522	535	524	527	527	529
New Zealand	521	521	517	531	518	532	519	532
Japan	520	530	520	521	520	518	529	539
Australia	515	513	513	523	513	524	514	527
Netherlands	508	519	504	510	506	514	526	522
Belgium	506	513	504	505	504	511	515	507

Table 18 PISA 2009 Report: Performance of 15 year old students in various subjects comparing countries' and economies' performance [45]

[44] Overcoming indigenous disadvantage, 2009
[45] http://www.oecd.org/dataoecd/54/12/46643496.pdf

In the list of countries that are above the OECD average in all evaluated scales, Australia takes 9th place and the US 17th place. Australia is 9th in reading, 10th in science and 15th in mathematics[46].

OECD PISA results indicate that Australian 15 year olds are significantly above the OECD average in all indicators of literacy, numeracy and science literacy; however, the issues highlighted in the TIMSS 2007 study are confirmed (Table 18).

	2003				2006				2009			
Subject	Average OECD	Average Australia	Boys Australia	Girls Australia	Average OECD	Average Australia	Boys Australia	Girls Australia	Average OECD	Average Australia	Boys Australia	Girls Australia
Reading	494	525	506	545	492	512	495	531	493	515	496	533
Math	500	524	526	521	498	520	527	512	496	514	519	509
Science	499	525	524	525	500	527	527	527	501	527	527	528
Physical systems					500	515	**527**	**502**				
Living systems					501	522	522	521				
Earth and Space Systems					500	530	**538**	**522**				
Scientific evidence					499	531	530	533				
Identifying scientific issues					499	535	525	546				
Explaining phenomena scientifically					500	520	527	513				
Knowledge about science					500	533	529	538				

Table 19 PISA results for 15 year olds in international comparison from 2003 to 2009 by gender

The 2006 results for Physics show that girls in Australia perform at the OECD average (Table 19), compared to the TIMSS 2007 study, in which Australian girls performed below international average.

Trends in PISA scores from 2000 to 2009

Reading scores have dropped 13 points, and after demographic adjustment, a 20 point increase in the proportion of students at the lower end of the performance scales has been found for reading, mathematics and to a degree in science (Tables 20-22).

[46] OECD (2011), *Lessons from PISA for the United States,* Strong Performers and Successful Reformers in Education, OECD Publishing. *http://dx.doi.org/10.1787/9789264096660-en*

Proficiency level	2000 (%)	2009 (%)
Below level 2	12.5	17.6
Level 5 and above	14.2	12.8

Table 20 Reading proficiency levels of Australian 15 year olds from 2000 to 2009

Proficiency level	2003 (%)	2009 (%)
Below level 2	14.3	19.8
Level 5 and above	15.9	16.4

Table 21 Mathematics proficiency levels of Australian 15 year olds

Proficiency level	2006 (%)	2009 (%)
Below level 2	12.9	14.6
Level 5 and above	12.6	14.5

Table 22 Science proficiency levels of Australian 15 year olds

Gender differences

There are numerous gender differences in the subcategories of each major category. For example, in the science sub topics assessed in 2006, girls performed better in some topics, and boys in others. Because all science subjects are eventually combined into one category, they appear to even each other out, and so it looks as though there is minimal gender difference in science related performance. One of the few categories in which girls performed better than boys was reading, the gender difference in this topic was 34 points in 2000 and 37 points in 2009 (Table 19).

Country	Proportion of top performing boys in reading who are also top performers in maths and science (%)	Proportion of top performing girls in reading who are also top performers in maths and science (%)	Gender difference %
Shanghai (top ranking country entity)	90.2	67.6	22
Chinese Taipei	88.6	67.7	21
Singapore	88.6	71.3	17
Australia	**80.9**	**53.6**	**27**

Table 23 Gender differences in top performance

Teachers and staff development for teaching

School teaching staff development

Science, and specifically physics, is distinguished as an area of teaching only at the secondary school level in Australia. However, more general elements are covered in primary schools.

The first real opportunity to introduce potential future scientists to physics is in primary school but primary school teachers are given little, if any, training in science to facilitate the development of science in a manner in which inquiring minds can obtain the correct answers and hence a foundation to science matters which affect them in everyday life. It is in primary school that they can first discover that science is part of life. It explains their environment, and knowledge of it can help to explain what is happening. There is a serious need to either provide considerably more staff development and resources for primary school teachers or develop specialist science and technology teachers who are able to better promote this important aspect of learning from an early stage.

While some attention is paid to the role of science curricula at primary level, of perhaps greater importance is the need for effective mathematics teaching. The students who become disengaged with maths before finishing primary school are unlikely to follow education paths to science[47].

The decline in the participation rates for secondary school science, particularly physics, is well documented by a number of studies and it has been happening for over 30 years. A key issue that has been identified by a number of studies is the inability to find sufficient numbers of teachers well versed in particular disciplines. This is best summed up in a recent report on this issue:[48:]

"A number of reports have focused on this issue for teachers of science (DEST, 2003; Harris et al., 2005). The findings include:

- *The number of students in secondary teacher education courses undertaking physics and chemistry subjects declined by 62% and 37% respectively between 1992 and 2000 (DEST, 2002, p. 11).*
- *Only a minority of junior to middle school teachers of science had studied physics beyond first year level (Harris, 2006; Harris et al., 2005).*
- *The percentage of schools that report experiencing difficulty in adequately staffing physics and chemistry classes, is 40% and 33% respectively (Harris, 2006).*
- *Low levels of science teaching and learning are biting particularly in non-metropolitan areas, where, in a recent national survey (Lyons, Cooksey, Panizzon, Parnell, & Pegg, 2006), schools in regional areas and those in remote areas are respectively twice and four times more likely to report it was 'very difficult' to fill vacant teaching positions in science, ICT and mathematics than those in urban areas.*
- *The shortage of teachers in the physical sciences will worsen, given that existing teachers tend to be in the older teaching demographic. Half of science teachers under 35 years of age have predominantly biology backgrounds, and have studied no physics at university (Harris, 2006)*

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[47] Maths? Why Not?, Final Report prepared for the Department of Education, Employment and Workplace Relations (DEEWR), http://www.dest.gov.au/NR/rdonlyres/6A16AECA-BC08-4187-A639-55AA9FACDBD2/21030/Maths_WhyNot_sml.pdf

[48] Opening up pathways: Engagement in STEM across the Primary-Secondary school transition, A review of the literature concerning supports and barriers to Science, Technology, Engineering and Mathematics engagement at Primary-Secondary transition. Commissioned by the Australian Department of Education, Employment and Workplace Relations, June, 2008)

- *There are high levels of disillusionment among current science teachers with work conditions and negative student attitudes. These are associated with low levels of expectation of staying in teaching in the longer term."*

The Australian Institute of Physics policy on teacher training recommends that a secondary school teacher should be educated in physics to at least three years beyond the highest level at which they teach. Furthermore there needs to be a greater focus on discipline knowledge than on pedagogy than is currently the practice.

According to the 2009 OECD Report on teaching and learning[49], in Australia in 2007-2008 approximately 60% of lower secondary teachers were female; 70% were younger than 50 years of age; 82% had a Bachelors degree; 13.7 % had a Masters degree; 2.2% had a degree higher than Masters; and 86% were permanently employed.

Teachers' starting salaries in 2007 were $US33,153 which was above the OECD average[50]. The average salary after 15 years of experience in lower secondary education in Australia ranks 9th out of 32 OECD countries.

According to this study, Australia was the only country that reported professional development needs below the OECD average in all 11 development areas, and on an overall development needs index ranked third lowest. Based on principals' reports on the level of induction and mentoring support for newly employed teachers, Australia ranked lowest in the analysed OECD countries. Average participation days in professional development across all teachers in Australia 8.7 days, significantly less than the 15.3 day OECD average.

Qualification of teachers to teach science, physics and mathematics

A 2006 study by the Australian Council of Deans of Science found the following:

The age profile for teachers showed a bulge of 'baby-boomers' in the 45-54 year age bracket that is particularly prominent for males, and would indicate an impending shortage of teachers.

Ninety-three per cent of the teachers surveyed were university trained, with the majority (90%) having studied science subjects in a Science Faculty rather than an Education Faculty.

Chemistry and biology were the most commonly and extensively studied university subjects. Far fewer respondents had studied physics and geology/earth sciences, particularly beyond first year. This pattern was most pronounced among younger teachers.

Fourteen per cent of respondents lacked a minor in any of the four subjects biology, chemistry, physics and geology. These teachers formed 16% of all teachers of junior school science, 12% of middle school science teachers and nearly 6% of senior school science teachers.

Nearly 8% of all respondents had not studied any of the four subjects biology, chemistry, physics and geology at university. These teachers formed 8% of all teachers who taught junior science, 5% of all teachers of middle school science and less than 2% of all teachers of senior school science.

Generally, the heads of science departments were satisfied with the science qualifications of the staff teaching science in their schools, but the levels of satisfaction were markedly lower for junior and middle school science than for senior school science.

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[49] Creating effective teaching and learning environments OECD 2009
http://www.oecd.org/dataoecd/17/51/43023606.pdf

[50] Education at a glance 2010: Education indicators. OECD 2010
http://www.oecd.org/document/52/0,3746,en_2649_39263238_45897844_1_1_1_1,00.html

Most (90%) heads of secondary school science departments defined the minimum qualification necessary to teach senior school science classes as an undergraduate university degree with a major in the relevant discipline. They expressed a preference, on balance, for teachers who had been prepared by science faculties.

Senior school biology teachers were the most highly trained in their discipline. Eighty-six per cent had a major in biology and almost 27% had studied biology to fourth-year. Only 4% of biology teachers had no tertiary background in the subject.

Nearly 43% of senior school physics teachers lacked a physics major, and one in four had not studied the subject beyond first-year.

Geology teachers had the lowest levels of discipline-specific qualifications. More than half of these teachers had not studied any geology at a tertiary level.

Compared to their older colleagues, younger teachers were more likely to have studied biology and less likely to have studied physics.

These findings may go a long way to explain the lower performances of the Year 4 and Year 8 students in the TIMSS 2007 and the PISA 2006 studies in the subjects physics and earth sciences, and the poorer performance of students in remote areas where younger and less qualified teachers are employed.

According to the TIMSS 2007 report,[51] 80% of Australian Year 4 Mathematics teachers and 49% of Year 8 Mathematics teachers are female. In Year 4, 77% of science teachers are female, and in Year 8, 50%. In Australia, approximately 50% of Year 4 and Year 8 students are taught by experienced teachers in their 30s and 40s.

In year 4, most Australian students have teachers with a qualification in primary/elementary education without a major or specialisation in science or mathematics, and only about 7% of students have teachers with a specialisation in mathematics (12% of the students have science teachers with a specialisation in science) (Table 24).

[51] TIMSS 2007: International Science Report
http://timssandpirls.bc.edu/TIMSS2007/PDF/TIMSS2007_InternationalScienceReport.pdf

	Percentage of students with teachers qualified by major area of study in their post-secondary education %
Year 4 Mathematics teachers	
Primary/Elementary Education with a Major or Specialisation in Mathematics	7 (1.7)
Primary/Elementary Education with a Major or Specialisation in Science but Not in Mathematics	5 (1.9)
Mathematics or Science Major or Specialisation Without a Major in Primary/ Elementary Education	1 (0.8)
Primary/ Elementary Education Without a Major or Specialisation in Mathematics or Science	84 (2.7)
Other	2 (0.9)
Year 8 Mathematics Teachers	
Education – Mathematics	46 (4.0)
Mathematics	49 (3.6)
Education – Science	25 (3.6)
Science	34 (3.4)
Education – General	32 (3.2)
Other	39 (3.6)
Year 4 Science Teachers	
Primary/ Elementary Education with a Major or Specialisation in Science	12 (2.5)
Primary/ Elementary Education with a Major or Specialisation in Mathematics but Not in Science	2 (0.6)
Science or Mathematics Major or Specialisation Without a Major in Primary/ Elementary Education	2 (0.8)
Primary/ Elementary Education Without a Major or Specialisation in Science or Mathematics	82 (2.9)
Other	2 (1.0)
Year 8 Science Teachers	
Education- – Science	63 (3.3)
Biology, Physics, Chemistry, or Earth Science	85 (2.4)
Education – Mathematics	16 (2.3)
Mathematics	22 (2.6)
Education – General	39 (4.1)
Other	30 (3.3)

Table 24 Percentage of students in year 4 and year 8 taught by teachers with various levels of qualification (by field of post-secondary specialisation) in Mathematics or Science

In 2007, Australia's Year 4 students were taught both mathematics and science by teachers significantly less qualified than the international average.

In Year 8, less than 50% of teachers had a mathematics degree or mathematics education qualification. In science, 85% of teachers had a science qualification.

Given the low percentage of females entering tertiary science courses with the aim of majoring in physics (20 to 25%), it is likely that in Year 8 less than 25% of female science teachers have a physics education beyond that received during their tertiary science education in chemistry, biology or earth Science.

There were significant differences from State to State, with the Northern Territory having the lowest proportion of teachers with a science background (21%), compared to NSW and Victoria with 94%.

Physics was the weakest area in Australia for both Year 4 and Year 8, in terms of how well prepared teachers felt they were to teach this topic. There is also a gender difference that shows that at the Year 4 level only 36% of female teachers and 40% of male teachers felt well prepared to teach Physics. At Year 8, 62% of female teachers and 77% of male teachers felt well prepared to teach physics, compared to biology, where 81% of female teachers and 71% of male teachers felt well prepared. For the mathematics subjects the figures for the male teachers were generally higher than for female teachers.

A 2005 study by Harris[52] for the Australian Council of Deans of Science found that in the middle school years almost 40% of physics teachers had no Physics tertiary background (Tables 25 and 26).

Highest level of university study completed	University subject areas			
	Biology %	Chemistry %	Physics %	Geology %
4th year or above	13.4	8.4	4.3	1.8
3rd year	36.5	24.2	8.5	6.4
2nd year	8.5	17.7	11.2	4.2
1st year	17.7	27.3	31.9	13.2
Nil	23.7	22.4	44	74.4

Table 25 Disciplinary background of junior school science teachers (n=598)

[52] Harris 2005: http://www.acds.edu.au/docs/teachsci.pdf

Highest level of university study completed	University subject areas			
	Biology %	Chemistry %	Physics %	Geology %
4th year or above	14.1	9.3	5.8	2.3
3rd year	34.1	26.0	9.8	7.3
2nd year	9.1	19.0	12.4	3.4
1st year	19.0	27.5	32.1	13.7
Nil	23.7	18.3	39.8	73.3

Table 26 Disciplinary backgrounds of the middle school science teachers (n=701)

Teaching environment

Students in Australia at both year 4 and year 8 levels experience mathematics and science teaching in a better environment in terms of numbers of students with disadvantaged backgrounds, resources, and safety than the international average. For example, students at schools with a higher level of resources for science education had higher performances than those at schools with lower resources. However, the resources in Australia are above international average and were not seen as the limiting factor for student performance by Australian school principals.

Students from indigenous backgrounds, due to their remoteness in location and the employment of more inexperienced and less qualified teachers in remote environments across the states, particularly the Northern Territory, have much lower achievements in both mathematics and the sciences. In the Northern Territory, students in the National Assessment Program – Literacy and Numeracy (NAPLAN) tests showed that only between 69% and 72% met Year 3, 5, 7 and 9 numeracy minimum standards, compared to students in all the other states where over 92% are at or above the minimum standard.[53] In the TIMSS 2007 assessment, only 37% of Year 8 indigenous students reached the intermediate level in Science, compared to 72% of non-indigenous students, and 32% versus 67% in mathematics. As numeracy is a critical enabling competency for studying science and especially physics, the pool of Northern Territory students that is equipped to progress from high school into a science or physics career is very small.

Increasing teacher effectiveness as a way forward

According to a 2010 study by the Grattan Institute on potential steps for increasing Australia’s school student scores in international comparison systems such as TIMSS and PISA[54], investing into increasing the effectiveness of teachers, especially the 14% currently least effective teachers, would improve PISA rankings of Australian students by 19 points and bring their performance into the top performing range of countries. This 19 point increase would translate to a 5% increase in student learning per year of schooling. Performance scores appear to be highly correlated with the economic performance of a country as there is a strong correlation between changes in test scores and changes in economic growth rates. Conservative estimates equate the increase by one standard deviation of test scores to 1% of GDP growth down the track.

The Grattan Institute proposed five mechanisms to increase teacher effectiveness:

[53] NAPLAN 2010 Summary Report 2010

[54] Investing in Our Teachers, Investing in Our Economy. Grattan Institute 2010

- Improve the quality of applicants to the teaching profession
- Improve the quality of teachers' initial education and training
- Evaluate and provide feedback to develop teachers once they enter the profession and are working in schools
- Recognise and reward effective teachers
- Move on ineffective teachers who have been unable to increase their effectiveness through development programs.

Increasing resources in education or reducing class sizes are not effective in increasing performance in students.

The higher education sector

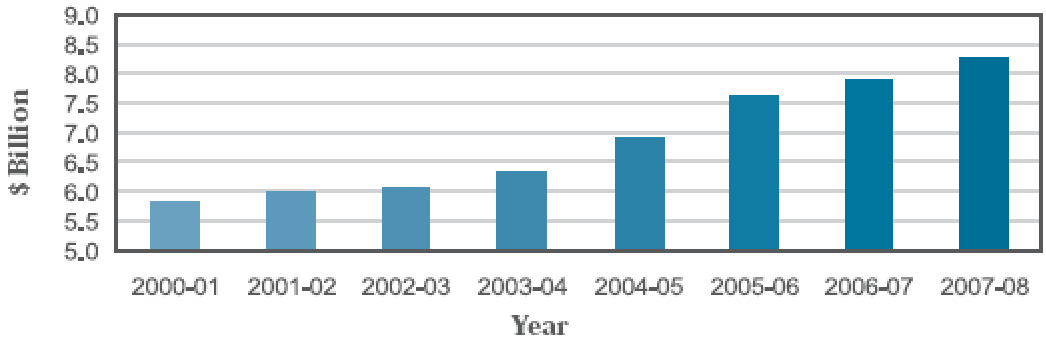
Key points

- Due to the poor information of the general public, parents and school students about physics as a basis for many professional careers it can be expected that there will be limited growth in secondary school physics classes in the near future. This limits the potential of all other Physics community sectors including the higher education sector to which the secondary school sector is a supplier. This most likely will translate into low undergraduate enrolments in science courses with majors and postgraduate education in Physics.
- Despite the increasing dependency of other disciplines on Physics knowledge (e.g. in medicine, biochemistry, geophysics, engineering etc.), the teaching of Physics to these disciplines does not match the growth experienced in these fields of teaching. This means the undergraduates in these disciplines are taught less physics as student cohorts a decade ago.
- The current growth in physics undergraduate enrolments to a large degree comes through growth in international students choosing Australian universities as destinations. Future growth in international student numbers will depend on the international reputation of the Physics departments which to a large degree is determined by its research excellence and the value delivered in balance to the cost of this education (exchange rates).
- Only approximately 400 individuals graduate each year with a Physics degree (graduate, Masters and PhD). Of these at least a quarter are international students of which many will leave Australia again and therefore will not be available for employment in Australian industry, research or teaching.
- The below average growth rate in the student numbers enrolled in the enabling sciences of Physical Sciences, Mathematical Sciences and Chemical Sciences will most likely mean that in the future the numbers of physicists that are required for effective collaboration with the growth disciplines and technology development in the private and government sectors will not be met.
- The higher education staffing profile shows breadth of both teaching and experimental expertise across all sub-disciplines with peaks in astronomy/astrophysics, condensed matter physics and optics and photonics.
- The gender balance of new enrolments in PhD programs has been worsening over the last decade from 27.6% to just over 21%.
- The gender balance of university staff shows that 21% are currently women. However, of the 100 newly appointed staff in 2010 only 12% were women.

In 2007, Australia spent 13.7% of all public spending on education, which is in excess of the OECD average of 13.0%. Spending on all types of educational institutions amounted to 4.3% of GDP; however, only 1.0% was spent on tertiary education institutions. This low figure compares to 7.8% and 2.3% of GDP for all and tertiary institutions respectively for Denmark, and 5.2% and 1.2% for all and tertiary institutions respectively for the USA. The OECD average is 5.2% and 1.2% of GDP[55].

Funding for Australia's universities has increased from 2000 to 2007[56] (Figure 8).

Higher Education Funding provided to Universities 2000-01 to 2007-08



Higher Education funding under HESA, HEFA and ARC provided to universities.
Total Commonwealth funding including research and loan programmes.
Figures also include 2006 Budget Decisions.

Figure 8 Higher Education Funding to Universities 2000 to 2007.

Source: DEST Website graphic

According to the Federal Government's Higher Education Report that was published in 2010,

- By 2012, all Australian Public universities will be funded on the basis of student demand;
- By 2020, 20% of higher education enrolments at undergraduate level should be people from low socio-economic backgrounds; and
- By 2025, 40% of all 25-34 years olds will have a qualification at the bachelor level or above.
-

[55] http://www.oecd.org/document/55/0,3746,en_2649_37455_46349815_1_1_1_37455,00.html

[56] http://www.dest.gov.au/portfolio_department/dest_information/publications_resources/resources/budget_information/budget_2007_2008/at_a_glance.htm

Universities

Number of universities providing physics higher education in Australia

There are 20 universities that have been accredited by the AIP since 2007 to provide Bachelor of Science courses with majors in physics or in one or more of its sub-disciplines. These universities are listed in Table 27. The full list of accredited programs is attached in Appendix 12.

University	Year of accreditation
Monash University	2007
University of Newcastle	2007
Queensland University of Technology	2008
Macquarie University	2008
University of New South Wales	2008
Murdoch University	2008
University of Western Australia	2008
Australian National University	2009
Flinders University	2009
Griffith University	2009
James Cook University	2009
University of Queensland	2009
University of Tasmania	2009
University of Technology Sydney	2009
University of Adelaide	2010
Latrobe University	2010
The University of Melbourne	2010
The University of Sydney	2010
University of Wollongong	2010
Curtin University	2011

Table 27 Australian Universities providing accredited Physics Bachelor of Science degrees

Number of staff working in universities

ERA data

The number of physicists working in universities is difficult to obtain. According to the ERA report 2010, in the 24 universities engaged in research in the physical sciences, there were 965 Full Time Equivalents (FTEs) engaged in the production of the research outputs over six years. This translates into 1,337 people. Scientists engaged in medical physics research are included within the other physical sciences (Table 28). If scientists engaged in mathematical physics and in geophysics are included into the staffing profile at universities, this adds another 186 physics scientists into the total count. These figures, however, do not give an accurate figure of the total headcount within universities and within sub-disciplines within the university sector due to the incomplete accounting of smaller research groups and not counting teaching physicists.

Discipline	Head count						
	Level E	Level D	Level C	Level B	Level A	Other	Total
Physical Sciences (02)	**143**	**109**	**174**	**309**	**216**	**387**	**1337**
Astronomy & Space Sciences	40	23	26	72	34	103	299
Atomic, Molecular, Nuclear, Particle and Plasma Physics	23	17	35	34	31	57	197
Classical Physics	4	6	7	12	7	25	61
Condensed Matter Physics	29	21	36	57	52	62	257
Optical Physics	24	23	31	64	46	48	237
Quantum Physics	9	7	11	22	11	11	72
Other Physical Sciences	13	11	28	48	35	80	214
Mathematical Physics (0105)	10	8	13	18	14	11	75
Geophysics ((0404)	16	10	19	20	16	37	117
All "Physics" Sub-disciplines	**169**	**127**	**206**	**347**	**245**	**435**	**1529**

Table 28 Research Staffing Profile of Physics Sub-disciplines as reported in ERA 2010

The distribution of staff across the sub-disciplines during the ERA publication assessment period, if mathematical physics and geophysics are included, shows that the largest sub-discipline is astronomical and space sciences; followed by condensed matter physics; optical physics; other physics; and atomic, molecular, nuclear, particle and plasma physics (Table 29). However, included in the 1529 staff are also, for example, engineers and other contributors to the physics-related publications.

Sub-discipline	Proportion in % of the total of 1529 people
Astronomical and Space Sciences	19.6
Atomic, Molecular, Nuclear, Particle and Plasma Physics	12.9
Classical Physics	4.0
Condensed Matter Physics	16.8
Optical Physics	15.5
Quantum Physics	4.7
Other Physical Sciences	14.0
Mathematical Physics	4.9
Geophysics	7.7

Table 29 Proportion of university staffing across physics sub-disciplines in the ERA 2010 Research Excellence Assessment

University physics staff survey

The Physics Decadal Plan Working Group examined the distribution of university staff by physics sub-discipline, and recent changes (within 2010) in staff numbers provide a review of physics in Australia today. These numbers were collected by surveying Heads of Physics in the first quarter of 2011.

The survey aimed to:

- Gather information about the present distribution of physicists between the sub-disciplines in higher education
- Identify trends in employment by sub-discipline
- Test if this is a useful tool to identify long-term trends if the data is collected on a regular basis

The survey forms were sent to the Heads of Physics mailing list. The survey responses were collected by a consultant from Rapid Invention Pty Ltd on behalf of the Physics Decadal Plan Working Group. Only aggregated results were presented to the Working Group. Individual responses were not identifiable were kept confidential by Rapid Invention Pty Ltd according to their privacy policy.

Responses were received from the following universities:

1. University of Melbourne
2. University of Sydney
3. University of Adelaide
4. University of New South Wales
5. University of Western Australia
6. University of Queensland
7. University of Newcastle
8. ANU
9. Monash University
10. La Trobe University
11. RMIT University
12. Flinders University
13. Curtin University
14. Murdoch University
15. Charles Darwin University
16. Wollongong University
17. Griffiths University
18. James Cook University
19. Macquarie University
20. University of Technology Sydney
21. University of Southern Queensland
22. Central Queensland University

The form employed by the survey was inspired by the report provided by the Institute of Physics (UK) on trends in UK Physics measured by the "Survey of Academic Appointments in Physics 2004–2008 United Kingdom and Ireland"[57]. The Institute of Physics survey spanned 47 physics departments and reported 1840 academic staff with a male to female ratio of 88% to 12%. Of these 1429 held positions classified as "lecturer", "reader and senior lecturer" or "professor". The survey did not include geophysicists and medical physicists who were not employed within physics departments but in other faculties such as earth sciences or medicine.

Present distribution of physics staff in Australian universities

By seniority

Just over 900 staff members were included in the 2011 survey of the 22 physics departments in Australia that responded to the survey. Of the 903 total, 274 (30%) were research fellows employed on research grants showing the importance of the funding agencies to support Australian physics research. Using the World Bank population figures[58] for Australia and the UK, this shows a ratio of 24,300 people per physicist in Australia and 33,600 per physicist in the UK. This perhaps shows that the Australian strength in physics is more concentrated in the University sector than in the UK.

The 900 staff in physics at Australian Universities, like the distribution also seen in the UK, is heavily weighted towards the senior end of the spectrum when it comes to continuing staff. As seen by the distribution in Figure 9, just over 140 staff members were at Level E which represents 32% of the total A-E personnel. Overall, 21% of the staff members were women who also comprise 22% of the total A-E personnel and 24% of the senior

[57] http://www.iop.org/publications/iop/2010/page_38419.html

[58] http://data.worldbank.org/data-catalog/world-development-indicators?cid=GPD_WDI, Australia: 21,875,000, UK: 61,838,000.

fellows. The percentage of women decreases from a high of 38% at level B to 12 % at level E. The need to support women into senior careers in physics was also identified during the decadal plan interview process.

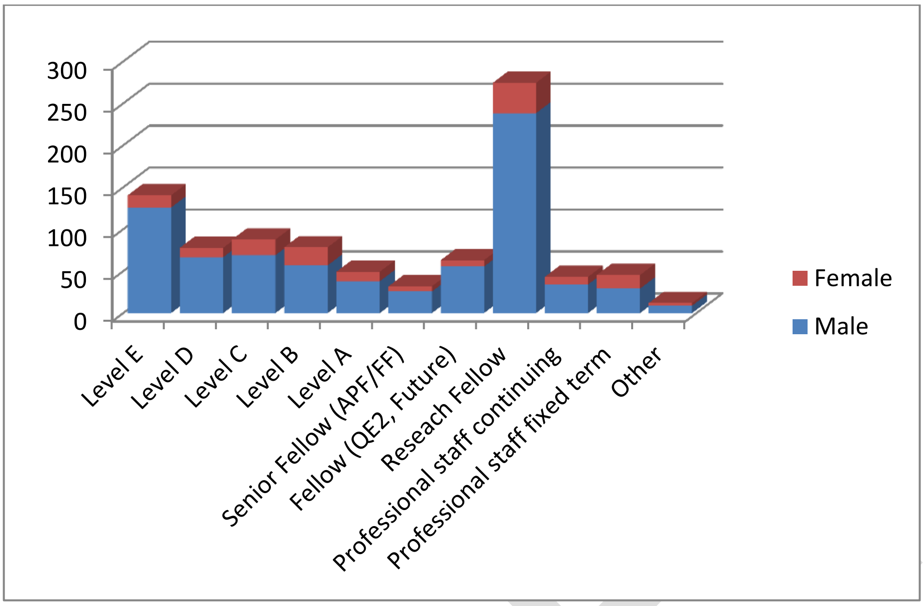


Figure 9 Distribution of staff in Australian university Physics by seniority

By sub-discipline

The present distribution of staff by sub-discipline in Australian Universities is shown in Figure 10. The traditional Australian strengths of astrophysics, optics and condensed matter physics is immediately evident from the numbers in these sub-disciplines. The figures should be interpreted in view of the significant changes in research programs triggered by the emergence of large teams working in the relatively new disciplines of quantum information and physical biosciences. As yet there is no consistent method of classifying people working at the boundaries of traditional sub-discipline areas. For the next physics decadal plan, a systematic taxonomy of interdisciplinary physics will need to be created. The small number of personnel in categories of “energy and power”, “chemical physics” and “industrial physics”, most likely indicate that personnel with interests in these areas are presently classified elsewhere. In the case of “chemical physics” many workers would probably consider themselves to be “condensed matter and materials” physicists.

Given the population of Australia it might be argued that having a number of areas of focus is an advantage for competing in these areas at international standards.

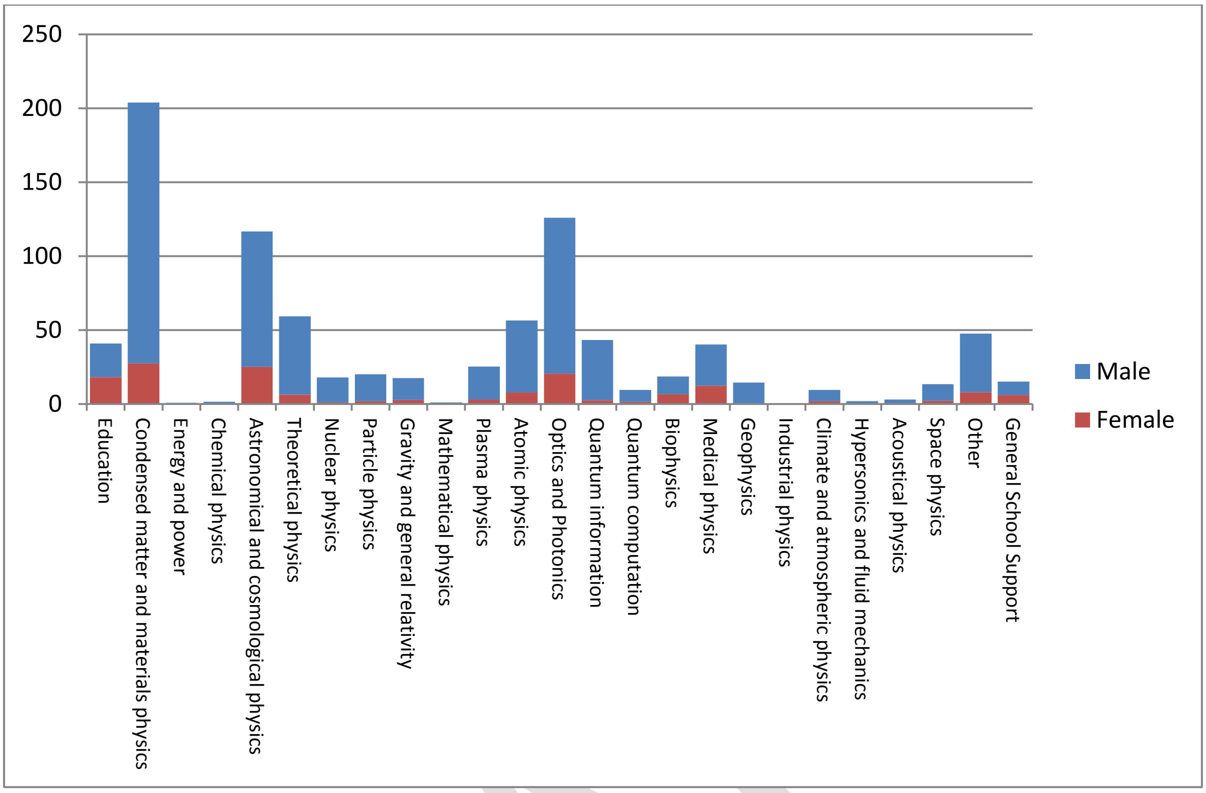


Figure 10 University Physics Staff distribution by sub-discipline

Changes in the past 12 months

To provide a snapshot of recent changes in areas of growth, the arrivals (Figure 11) and departures (Figure 12) of staff by sub-discipline were also surveyed. Here, a finer grained measurement was done where separate categories of theory and experiment were allocated within each sub-discipline. Not surprisingly, the sub-disciplines that were already the largest in absolute numbers were also the beneficiaries of the largest imports of new personnel. Just on 100 new personnel came into physics in 2010 with 12% of these women.

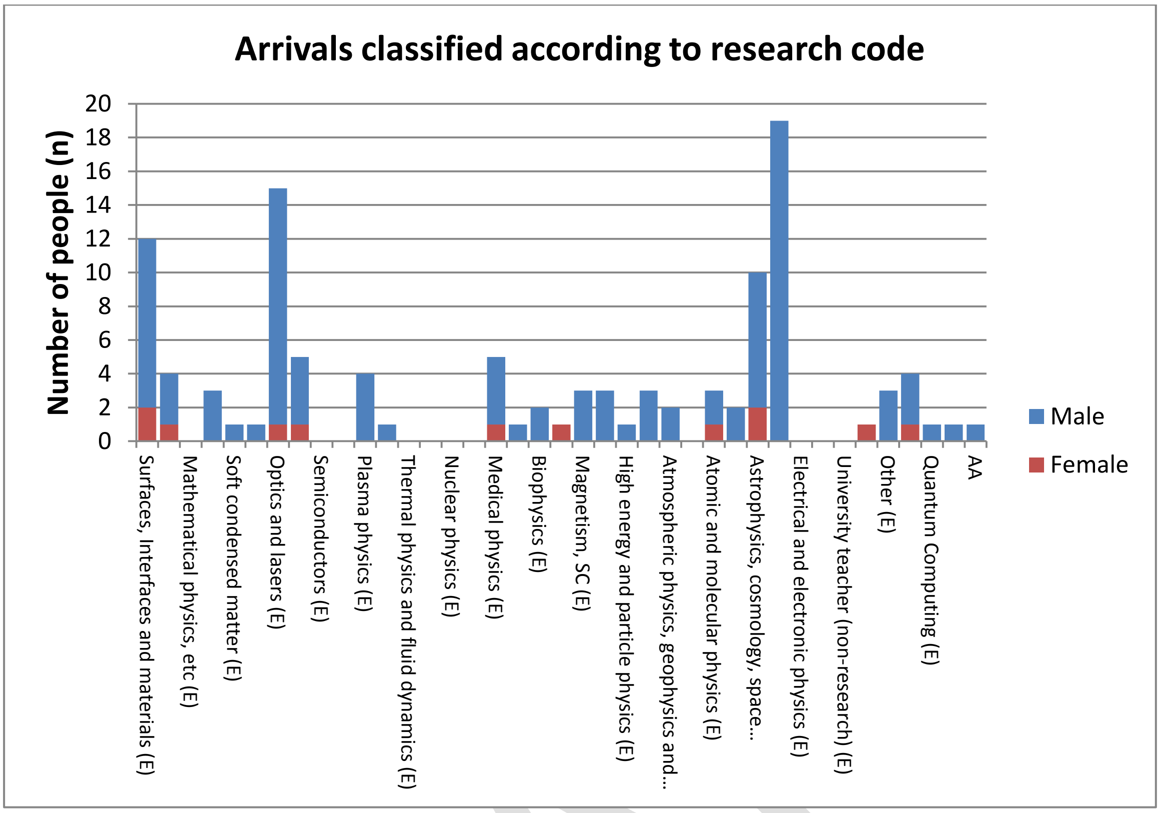


Figure 11 Arrivals of university Physics staff by sub-discipline

The good news for Physics was the fact that the 100 arrivals were balanced by only 50 departures over the same period (Figure 12). Once again, the largest sub-discipline areas saw the most movement.

With regard to how the growth was distributed by sub-discipline, astrophysics appears the major beneficiary with just under half of the net gain in personnel joining this community.

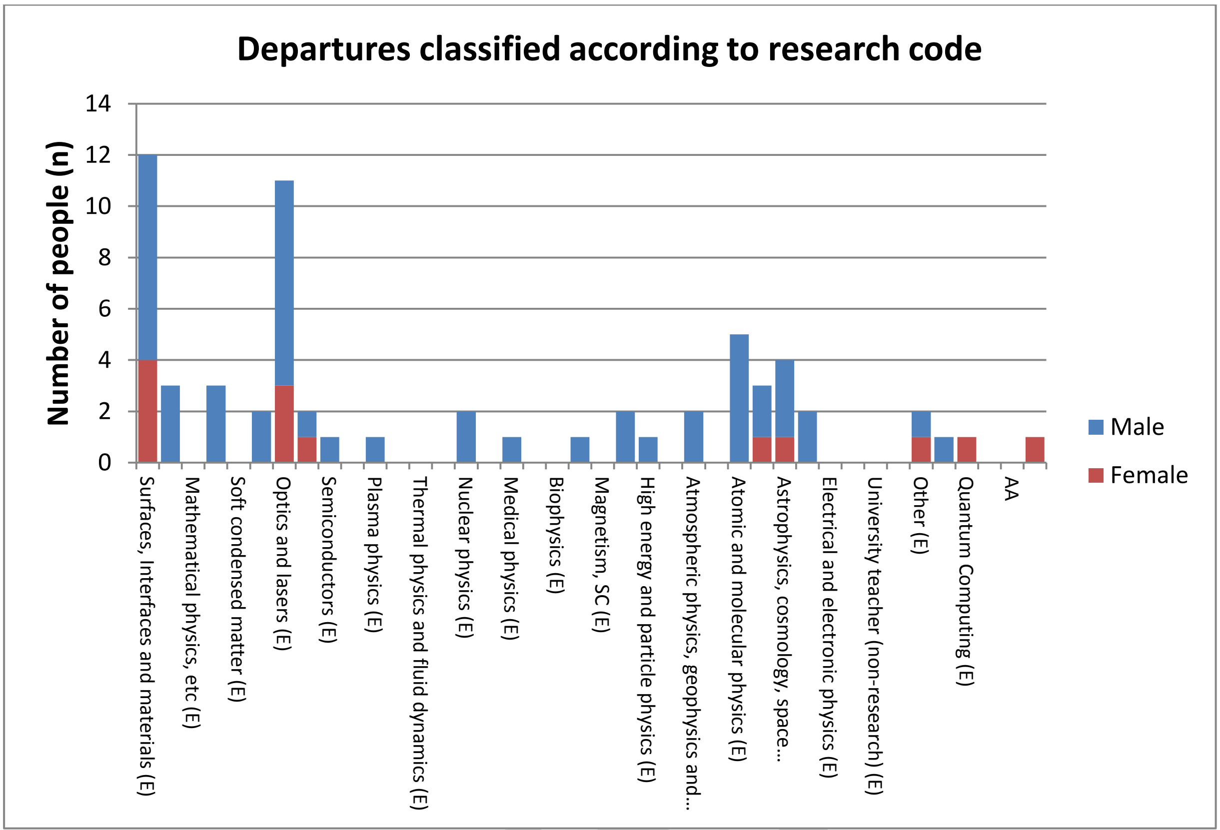


Figure 12 Departures of university Physics staff by sub-discipline

The net change over the past 12 months is shown in Figure 13. Given the relativity small numbers of people joining and departing the various sub-disciplines it is not possible to identify systematic trends, however the growth in personnel in astrophysics it notable. This possibly reflects the fact that "Space science and Astronomy" was a targeted discipline area in both round 1 and 2 of the Super Science Fellowship scheme[59] and funded 33 new fellows. The other two targeted discipline areas ("Marine and climate science" and "Future industries") may also have funded fellows in physics, but not necessarily collected into a single specific sub-discipline area.

However it would be interesting to see if these trends are reflected also in the number of students studying in ach discipline and if the same trends are also seen in the government sector. In future surveys it would be interesting to use a longer time period to capture greater numbers and address the low statistics of the sample.

[59] http://www.arc.gov.au/ncgp/ssf/SSF1011_selrpt.htm

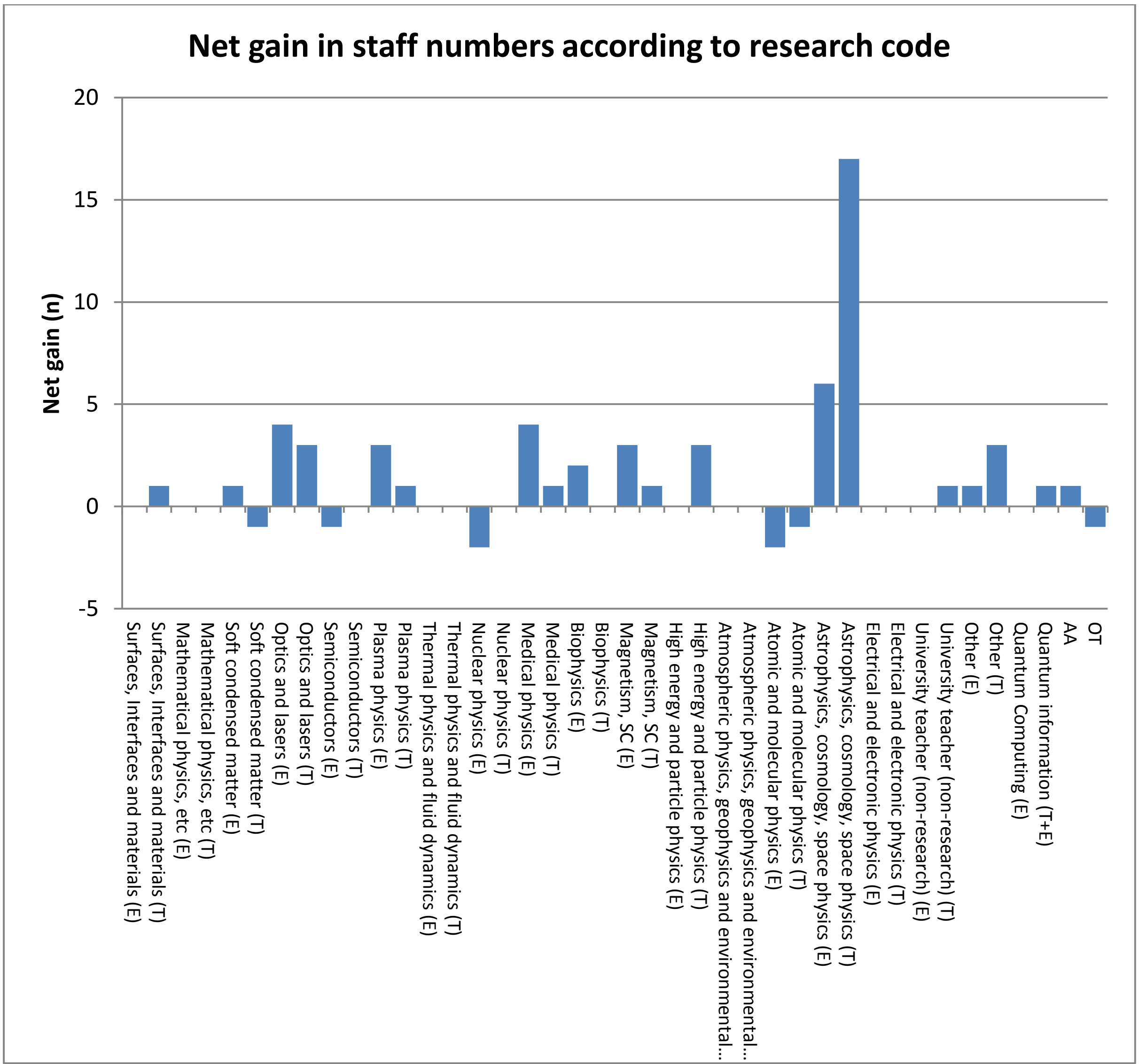


Figure 13 Net change in university staff by sub-discipline

Student to staff ratio

Student to staff ratio has been increasing in the university environment and is thought to be one factor which could negatively influence student retention and further study[60]. However, at this point in time there are no data available on student to staff ratios in the core physics courses at the universities in Australia.

Undergraduate and postgraduate education

It is difficult to obtain consistent data on the teaching of physics to students in tertiary education. This is due to changes in the metrics employed from year to year and the variability in skills of coders who report on teaching and enrolments within universities from year to year.

[60] Transforming Australia's Higher Education System. Commonwealth of Australia 2009

Dobson, in his 2007 report[61], states that "The figures indicate a decline of the proportion of students in the mathematical sciences in the period 1989 to 2004 from 17.3% to 9.8%. The other enabling sciences (physical and chemical sciences) also declined as a proportion of an 'average' science degree. The biological sciences' proportion, on the other hand, has increased by nearly 12% in the period 1989 to 2005, increasing from less than 25% to over 36%. It is clear that the enabling sciences' proportion has dropped considerably since 1989."

A current review of DEST/DEEWR data for 2002 to 2009 for this report, using an updated dataset, indicates that for Physics it is most likely that differences in coding of courses as either physics & astronomy, or as physics or astronomy has led to substantial swings between years. An apparent drop in enrolments in courses in 'physics & astronomy' may be due to re-coding of these courses as either astronomy or physics in the same years. For this reason, in this plan only the sub-totals that include all three combinations for 'physical sciences' will be used. A full set of Tables and field of education and discipline group codes is provided in Appendix 11.

For the purpose of this plan we assume that the data on PhD enrolments and completions would provide the best indicators for trends in physics tertiary education.

Undergraduate education

In contrast to the previous reports by Dobson in 2007, there was a 13.3% increase from 2002 to 2009 in student load taught in physical sciences at all course levels (undergraduate, Masters and PhD courses) and all fields of education (Table 30). These courses include physics taught to BSc students, engineers, arts students, biologists and students from other disciplines, regardless of whether the course is provided by a physics department or, for example, by an engineering faculty. However, the growth rate of 13.3% represents the lowest growth rate over most of the past decade compared to the average growth rate of 28.3% for all teaching across the natural and physical sciences. It can be concluded that despite the increasing dependency of other disciplines on physics knowledge (e.g. in medicine, biochemistry, geophysics, engineering etc), the teaching of physics to these disciplines does not match the growth experienced in these fields of teaching. Within the physical sciences, the proportional distribution of the individual sciences has stayed almost the same from 2002 to 2009, indicating that either the course offerings or course structures have changed little during this period, or that changes are not apparent due to constraints of reporting codes.

61 Dobson, I.R. Sustaining Science: University Science in the 21st Century. A study commissioned by the Australian Council of Deans of Science February 2007.

Discipline Group	2002	2003	2004	2005	2006	2007	2008	2009	Growth - No.	Growth - %
No.										
Mathematical Sciences	20519	20906	21127	20326	20971	22099	22968	26216	5696	27.8%
Physical Sciences										
Physics & Astronomy	1146	1105	531	294	122	131	128	133	-1013	-88.4%
Physics	3580	3592	4115	4099	4449	4653	4657	5170	1590	44.4%
Astronomy	267	286	323	300	302	291	309	354	86	32.3%
Sub-total	4994	4984	4970	4693	4873	5075	5094	5657	663	13.3%
Chemical Sciences	7621	7828	8060	8069	8277	8614	8606	9332	1712	22.5%
Earth Sciences	3897	3864	3661	3432	3508	3650	3919	4746	849	21.8%
Biological Sciences	30512	31434	32030	32645	33970	35584	35972	38434	7922	26.0%
Other Sciences	6192	6580	7560	7284	7868	8516	8890	10225	4032	65.1%
All Natural & Physical Sciences	**73735**	**75597**	**77407**	**76449**	**79467**	**83538**	**85449**	**94610**	**20874**	**28.3%**
Per Cent										
Mathematical Sciences	27.8%	27.7%	27.3%	26.6%	26.4%	26.5%	26.9%	27.7%		
Physical Sciences										
Physics & Astronomy	1.6%	1.5%	0.7%	0.4%	0.2%	0.2%	0.1%	0.1%		
Physics	4.9%	4.8%	5.3%	5.4%	5.6%	5.6%	5.5%	5.5%		
Astronomy	0.4%	0.4%	0.4%	0.4%	0.4%	0.3%	0.4%	0.4%		
Sub-total	6.8%	6.6%	6.4%	6.1%	6.1%	6.1%	6.0%	6.0%		
Chemical Sciences	10.3%	10.4%	10.4%	10.6%	10.4%	10.3%	10.1%	9.9%		
Earth Sciences	5.3%	5.1%	4.7%	4.5%	4.4%	4.4%	4.6%	5.0%		
Biological Sciences	41.4%	41.6%	41.4%	42.7%	42.7%	42.6%	42.1%	40.6%		
Other Sciences	8.4%	8.7%	9.8%	9.5%	9.9%	10.2%	10.4%	10.8%		
All Natural & Physical Sciences	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**		

Table 30 Student load 2002 – 2009: Teaching to students enrolled in courses at all course levels in All Fields of Education, by Discipline Group

Source: DEST/DEEWR Aggregated Data Set 'UEAGyyyy' for years 2002 – 2009. Note: This table shows all teaching in 01 Natural and Physical Sciences disciplines to students in all university courses at all course levels. (Compiled by Ian Dobson 2011 for the Physics Decadal Plan Working Group)

Table 31 shows that all natural and physical sciences course enrolments increased from 2002 to 2009 by 20%. In 2009, 3170 undergraduate and postgraduate science students undertook physics courses. This growth rate is 5.1% lower than the average of 25.1% for all natural and physical sciences.

The highest growth rate of 53% was experienced by the other sciences, which include medical science; forensic science; food science and biotechnology; laboratory technology; pharmacology; and natural and physical sciences not classified elsewhere.

The high increase in number of students in the other natural and physical sciences from 3372 students in 2002 to 5158 in 2009, and the increase by 3985 students in the biological sciences, would suggest that there would be an increasing demand for physicists teaching physics to these students in the future. However, the proportion of students at all levels studying physics has not changed substantially over the last decade, from 7.4% to 7.1% of all natural and physical science students. The below average growth rate in the student numbers enrolled in the enabling sciences of physical sciences, mathematical sciences and chemical sciences will most likely mean that in the future the numbers of physicists that are required for effective collaboration with the growth disciplines and technology development in the private and government sectors will not be met.

Only slightly more than 400 students complete a primary or secondary physical sciences course each year (Table 32). This is particularly worrying as the proportion of domestic students completing their courses at all course levels has decreased for all enabling science disciplines (mathematical physical, physical sciences, chemical sciences) and also for earth sciences and biological sciences. The only sciences showing any growth in domestic student numbers are the other natural and physical sciences.

Discipline Group	2002	2003	2004	2005	2006	2007	2008	2009	Growth - No.	Growth - %
No.										
Mathematical Sciences	4988	5175	5269	4034	5133	5100	5272	6067	1079	21.6%
Physical Sciences										
Physics & Astronomy	668	662	299	203	54	52	60	79	-589	-88.2%
Physics	1763	1828	2224	1997	2595	2578	2560	2798	1035	58.7%
Astronomy	211	236	268	258	258	247	258	293	83	39.2%
Sub-total	2641	2727	2790	2458	2907	2877	2878	3170	529	20.0%
Chemical Sciences	5135	5303	5491	4653	5725	5822	5756	6130	995	19.4%
Earth Sciences	2414	2378	2218	1803	2137	2286	2462	2945	530	22.0%
Biological Sciences	16964	17701	18347	16602	19271	19788	19905	20949	3985	23.5%
Other Sciences	3372	3754	4132	3640	4245	4537	4650	5158	1786	53.0%
All Natural & Physical Sciences	**35514**	**37038**	**38247**	**33190**	**39418**	**40410**	**40923**	**44418**	**8904**	**25.1%**
Per Cent										
Mathematical Sciences	14.0%	14.0%	13.8%	12.2%	13.0%	12.6%	12.9%	13.7%		
Physical Sciences										
Physics & Astronomy	1.9%	1.8%	0.8%	0.6%	0.1%	0.1%	0.1%	0.2%		
Physics	5.0%	4.9%	5.8%	6.0%	6.6%	6.4%	6.3%	6.3%		
Astronomy	0.6%	0.6%	0.7%	0.8%	0.7%	0.6%	0.6%	0.7%		
Sub-total	7.4%	7.4%	7.3%	7.4%	7.4%	7.1%	7.0%	7.1%		
Chemical Sciences	14.5%	14.3%	14.4%	14.0%	14.5%	14.4%	14.1%	13.8%		
Earth Sciences	6.8%	6.4%	5.8%	5.4%	5.4%	5.7%	6.0%	6.6%		
Biological Sciences	47.8%	47.8%	48.0%	50.0%	48.9%	49.0%	48.6%	47.2%		
Other Sciences	9.5%	10.1%	10.8%	11.0%	10.8%	11.2%	11.4%	11.6%		
All Natural & Physical Sciences	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**		

Table 31 Teaching to students enrolled in courses at all course levels (undergraduate, Masters and PhD levels) in Natural and Physical Sciences, by Discipline Group

Source: DEST/DEEWR Aggregated Data Set 'UEAGyyyy' for years 2002 – 2009. Note: This table shows all teaching in 01 Natural and Physical Sciences disciplines to students in university courses in the Natural & Physical Sciences field of education, at all course levels. These are the official figures. Those in 'Sustaining Science (2007)' were adjusted for NPS to take account of changes in the classification schemes at Monash that affected the time series. (Compiled by Ian Dobson 2011 for the Physics Decadal Plan Working Group)

Field of Education	2002	2003	2004	2005	2006	2007	2008	2009	Growth - No.	Growth - %
Mathematical Sciences	682	702	675	666	689	728	717	715	33	4.8%
Physical Sciences										
Physics & Astronomy	79	116	89	67	68	59	35	69	-10	-12.7%
Physics	237	303	272	284	331	312	347	283	46	19.4%
Astronomy	23	43	60	56	58	64	53	59	36	156.5%
Sub-total	339	462	421	407	457	435	435	411	72	21.2%
Chemical Sciences	517	512	572	441	516	522	563	501	-16	-3.1%
Earth Sciences	512	435	523	429	340	330	359	393	-119	-23.2%
Biological Sciences	3803	4088	4281	4200	4155	4067	4258	4146	343	9.0%
Other Natural and Physical Sciences Courses	7305	7378	8295	9101	9592	10001	9988	10001	2696	36.9%
Sub-total	**13158**	**13577**	**14767**	**15244**	**15749**	**16083**	**16320**	**16167**	**3009**	**45.7%**
Sub-total secondary courses	815	866	889	1001	1078	1022	992	926	111	13.6%
Total	**13973**	**14443**	**15656**	**16245**	**16827**	**17105**	**17312**	**17093**	**3120**	**22.3%**

Table 32 Course completions of Natural and Physical Sciences (NPS) Students in NPS as Primary or Secondary Course

Source: DEST/DEEWR Aggregated Data Set 'UEAGyyyy' for years 2002 – 2009. These are the official figures. Those in 'Sustaining Science (2007)' were adjusted for NPS to take account of changes in the classification schemes at Monash that affected the time series. (Compiled by Ian Dobson 2011 for the Physics Decadal Plan Working Group)

Student mobility

In the context of this discussion the terms, foreign, international, and overseas student are used synonymously with a student not having Australian citizenship status. According to an OECD study in 2008, 20.6% of students in the tertiary education segment across all disciplines in Australia were international students, and foreign enrolments (i.e. by non-citizens) were 23.6%[62]. The preferred levels and types of education were Tertiary type A programs (81.3%), type B programs (14.4%) and advanced research programs (4.3%). The distribution of international students in tertiary education by field of education showed that only 12.3% enrolled in sciences, 10.3% in engineering and 55.8% in social sciences, business and law.

There is a trend for increased internationalisation of tertiary education. The number of foreign students enrolled outside their country of origin increased between 1975 and 2008 from 0.8 million to 3.3 million. Foreign students enrolled in OECD countries from 2000 to 2008 increased from 1.587 million to 2.646 million.

The destination of choice for the majority of foreign students in 2008 was the USA (18.7%), 10.0% went to the United Kingdom, 7.3% to Germany, 7.3% to France. Australia, with 6.9% was the 5th most sought after destination before Canada (5.5%), the Russian Federation (4.3%) and Japan (3.8%).

Foreign students are most numerous in Australia, Austria, the United Kingdom, Switzerland and New Zealand. Although the USA attracts most foreign students, they make up less than 4% of the US student population.

In 2008, less than 25% of foreign students in Australia enrolled in science and related courses, with 65% enrolling in humanities, arts, services and business related topics, compared with the US where more than 35% enrolled in science related courses . Students in the Sciences were 12.3% for Australia and 19.7% for the USA.

The analysis of Australian tertiary education for this report showed that overall in 2002, 10.6% of course completions for all levels in all natural and physical sciences were attributed to overseas students. By 2009 that figure had risen to 21% (Table 33).

The physical sciences have the lowest participation rate of women in all the natural and physical sciences (Table 34). The participation rate of women in the physical sciences, as indicated by the course completion rate in the years from 2002 to 2009, has declined by 4% from 25.4% to 20.2% of physical sciences students completing their courses. This is less than half of the completion rate in mathematics which is around 40%, and less than half the average of 54.1% for all the natural and physical Sciences. In 2009, only 83 women completed their physical science courses at undergraduate and postgraduate level. Although there was an increase in course completions for male students, the overall numbers are very small compared to the biological sciences and the other Natural and physical sciences but significantly larger than for mathematical and chemical sciences. In 2009, across all of Australia only 75 more students in completed their physical sciences courses compared to 2002.

[62] Education at a glance 2010: OECD indicators. OECD 2010 http://www.oecd.org/document/52/0,3746,en_2649_39263238_45897844_1_1_1_1,00.html

Field of Education / Citizenship Status	2002	2003	2004	2005	2006	2007	2008	2009	Growth - No.	Growth - %
Mathematical Sciences										
Overseas	77	90	99	97	97	134	143	153	76	98.7%
Domestic	605	612	576	569	592	594	574	562	-43	-7.1%
Sub-total	682	702	675	666	689	728	717	715	33	4.8%
Overseas % of All	11.3%	12.8%	14.7%	14.6%	14.1%	18.4%	19.9%	21.4%	230.3%	
Physical Sciences										
Overseas	60	85	86	66	100	115	112	136	76	126.7%
Domestic	279	377	335	341	357	320	323	275	-4	-1.4%
Sub-total	339	462	421	407	457	435	435	411	72	21.2%
Overseas % of All	17.7%	18.4%	20.4%	16.2%	21.9%	26.4%	25.7%	33.1%	105.6%	
Chemical Sciences										
Overseas	56	63	59	64	89	85	104	123	67	119.6%
Domestic	461	449	513	377	427	437	459	378	-83	-18.0%
Sub-total	517	512	572	441	516	522	563	501	-16	-3.1%
Overseas % of All	10.8%	12.3%	10.3%	14.5%	17.2%	16.3%	18.5%	24.6%	-418.8%	
Earth Sciences										
Overseas	40	48	56	49	48	45	77	91	51	127.5%
Domestic	472	387	467	380	292	285	282	302	-170	-36.0%
Sub-total	512	435	523	429	340	330	359	393	-119	-23.2%
Overseas % of All	7.8%	11.0%	10.7%	11.4%	14.1%	13.6%	21.4%	23.2%	-42.9%	
Biological Sciences										
Overseas	380	452	561	669	724	767	852	850	470	123.7%
Domestic	3423	3636	3720	3531	3431	3300	3406	3296	-127	-3.7%
Sub-total	3803	4088	4281	4200	4155	4067	4258	4146	343	9.0%
Overseas % of All	10.0%	11.1%	13.1%	15.9%	17.4%	18.9%	20.0%	20.5%	137.0%	
Other Natural and Physical Sciences										
Overseas	780	930	1371	1647	1812	2052	2022	2038	1258	161.3%
Domestic	6525	6448	6924	7454	7780	7949	7966	7963	1438	22.0%
Sub-total	7305	7378	8295	9101	9592	10001	9988	10001	2696	36.9%
Overseas % of All	10.7%	12.6%	16.5%	18.1%	18.9%	20.5%	20.2%	20.4%	46.7%	
All Natural & Physical Sciences FoEs										
Overseas	1393	1668	2232	2592	2870	3198	3310	3391	1998	143.4%
Domestic	11765	11909	12535	12652	12879	12885	13010	12776	1011	8.6%
Total	**13158**	**13577**	**14767**	**15244**	**15749**	**16083**	**16320**	**16167**	**3009**	**22.9%**
Overseas % of All	10.6%	12.3%	15.1%	17.0%	18.2%	19.9%	20.3%	21.0%	66.4%	

Table 33 Course completions of Natural and Physical Science Students for all course levels (undergraduate, Masters and PhD levels), by Citizenship Status

Source: DEST/DEEWR Aggregated Data Set 'UEAGyyyy' for years 2002 – 2009. These are the official figures. Those in 'Sustaining Science (2007)' were adjusted for NPS to take account of changes in the classification schemes at Monash that affected the time series. (Compiled by Ian Dobson 2011 for the Physics Decadal Plan Working Group)

Field of Education / Gender	2002	2003	2004	2005	2006	2007	2008	2009	Growth - No.	Growth - %
Mathematical Sciences										
Female	269	286	264	244	249	279	288	282	13	4.8%
Male	413	416	411	422	440	449	429	433	20	4.8%
Sub-total	682	702	675	666	689	728	717	715	33	4.8%
Female % of All	39.4%	40.7%	39.1%	36.6%	36.1%	38.3%	40.2%	39.4%	39.4%	
Physical Sciences										
Female	86	118	103	89	106	92	87	83	-3	-3.5%
Male	253	344	318	318	351	343	348	328	75	29.6%
Sub-total	339	462	421	407	457	435	435	411	72	21.2%
Female % of All	25.4%	25.5%	24.5%	21.9%	23.2%	21.1%	20.0%	20.2%	-4.2%	
Chemical Sciences										
Female	216	210	261	200	243	247	246	219	3	1.4%
Male	301	302	311	241	273	275	317	282	-19	-6.3%
Sub-total	517	512	572	441	516	522	563	501	-16	-3.1%
Female % of All	41.8%	41.0%	45.6%	45.4%	47.1%	47.3%	43.7%	43.7%	-18.8%	
Earth Sciences										
Female	186	148	174	176	124	144	139	142	-44	-23.7%
Male	326	287	349	253	216	186	220	251	-75	-23.0%
Sub-total	512	435	523	429	340	330	359	393	-119	-23.2%
Female % of All	36.3%	34.0%	33.3%	41.0%	36.5%	43.6%	38.7%	36.1%	37.0%	
Biological Sciences										
Female	2321	2486	2625	2577	2533	2375	2477	2410	89	3.8%
Male	1482	1602	1656	1623	1622	1692	1781	1736	254	17.1%
Sub-total	3803	4088	4281	4200	4155	4067	4258	4146	343	9.0%
Female % of All	61.0%	60.8%	61.3%	61.4%	61.0%	58.4%	58.2%	58.1%	25.9%	
Other Natural and Physical Sciences										
Female	4161	4235	4846	5293	5526	5792	5692	5605	1444	34.7%
Male	3144	3143	3449	3808	4066	4209	4296	4396	1252	39.8%
Sub-total	7305	7378	8295	9101	9592	10001	9988	10001	2696	36.9%
Female % of All	57.0%	57.4%	58.4%	58.2%	57.6%	57.9%	57.0%	56.0%	53.6%	
All Natural & Physical Sciences FoEs										
Female	7239	7483	8273	8579	8781	8929	8929	8741	1502	20.7%
Male	5919	6094	6494	6665	6968	7154	7391	7426	1507	25.5%
Total	**13158**	**13577**	**14767**	**15244**	**15749**	**16083**	**16320**	**16167**	**3009**	**22.9%**
Female % of All	55.0%	55.1%	56.0%	56.3%	55.8%	55.5%	54.7%	54.1%	49.9%	

Table 34 Course completions of Natural and Physical Sciences Students for all course levels (undergraduate, Masters and PhD levels), by Gender

Source: DEST/DEEWR Aggregated Data Set 'UEAGyyyy' for years 2002 – 2009. These are the official figures. Those in 'Sustaining Science (2007)' were adjusted for NPS to take account of changes in the classification schemes at Monash that affected the time series. (Compiled by Ian Dobson 2011 for the Physics Decadal Plan Working Group)

Postgraduate education

PhD enrolment data can be seen as a reliable indicator for trends in a science discipline as they provide a specific dataset that cannot be easily misinterpreted or miscoded from year to year.

Approximately 20% of all PhD enrolments in Australia are in the natural and physical sciences, with a growth of almost 40% from 2002 to 2009. In 2009, 9163 students were enrolled in a PhD program in the natural and physical sciences, an increase of 39.8% from 2002 (Table 35). Of these, 11% or 989 students had been enrolled in a physical sciences PhD program. The increase of 40.9% over the period 2002-9 for physical science PhD enrolments was slightly above the average for all natural and physical sciences PhD enrolments.

A drastic and worrying decrease in PhD enrolments of 16.2% for the earth sciences (Table 36), which includes geophysics, is most likely the result of earth sciences graduates choosing to enter employment in the mining sector straight after graduation, instead taking advantage of the high salaries made available by the mining resource boom rather than starting postgraduate education. This will lead to a reduced availability of research trained earth scientists and academics for teaching these subjects in future years.

As there is no distinct industry boom that would selectively favour the employment of physics graduates and there is little understanding of the value physicists can bring to even small to medium sized industry companies by both industry and students alike, a PhD may be a stop-gap measure after graduation for many physics graduates.

The number of PhD students enrolled in the physical sciences increased by 287 individuals from 2002 to 2009. Of these, 131 were overseas students. The proportion of overseas students enrolled in physical sciences PhD courses rose from 15.1% in 2002 to 26.9% in 2009. This represents growth rate that is similar to biology, chemistry and other natural and physical sciences. The highest growth in the proportion of overseas PhD course enrolments was seen in the earth sciences which include geophysics, from 18.1% to 43.9%. In this discipline group the participation rate of domestic PhD course enrolments fell by 44.2% from 2002 to 2009. (Table 37).

The numbers of males enrolled in PhD courses rose from 371 in 2002 to 608 in 2009 (an increase of 64%), whilst the number of females increased from only 141 to 166 (an increase of only 17.4%) in the same timeframe (Table 38). Therefore the overall participation rate of women in physics PhD courses has decreased from 27.6% in 2002 to 21.4% in 2009. The fact that women almost maintained their presence in earth science PhD enrolments at the 2002 levels whilst their male counterparts decreased their participation rate in PhD course enrolments by almost 28% over the same timeframe may indicate that women find it difficult or undesirable to find employment in the mining and resources industry.

Each year, between 110 (2002) and 151 PhD students (2009) complete their higher degree course program. While these numbers fluctuate considerably, the proportion due to overseas students has increased more steadily from 17.3% to 25.8% of all physical sciences PhD completions over that time period (Table 39).

The number of women completing a PhD each year in the physical sciences in Australia is very low, fluctuating between 24 and 47 within the time period measured. Similarly low numbers are found for women in the other enabling disciplines of mathematics and chemistry, and in earth sciences but not in biology and the other natural and physical sciences.

The low attractiveness of the enabling sciences, especially the Physical Sciences for women can be best put in perspective by the fact that of the 1388 PhD completions in 2009 in all the natural and physical sciences only 31 women completed their PhD in the physical sciences, the same number as in mathematics and earth sciences.

Field of Education	2002	2003	2004	2005	2006	2007	2008	2009	Growth - No.	Growth - %
Natural and Physical Sciences	6553	6884	7317	8134	8404	8677	8730	9163	2610	39.8%
Information Technology	1000	1134	1359	1497	1619	1537	1528	1602	602	60.2%
Engineering and Related Technologies	3374	3699	3985	4110	4199	4340	4547	5047	1673	49.6%
Architecture and Building	425	468	472	469	513	525	550	617	192	45.2%
Agriculture, Environmental and Related Studies	1517	1581	1629	1760	1815	1869	2063	2121	604	39.8%
Health	4663	4976	5218	4736	5185	5533	5618	5976	1313	28.2%
Education	3380	3454	3428	3490	3490	3499	3445	3415	35	1.0%
Management and Commerce	3008	3128	3242	3359	3459	3521	3494	3606	598	19.9%
Society and Culture	8957	9163	9530	9908	10214	10284	10612	10881	1924	21.5%
Creative Arts	1163	1388	1505	1490	1613	1642	1779	1864	701	60.3%
Total	**34040**	**35875**	**37685**	**38953**	**40511**	**41427**	**42366**	**44292**	**10252**	**30.1%**
Natural and Physical Sciences % of Total	**19.3%**	**19.2%**	**19.4%**	**20.9%**	**20.7%**	**20.9%**	**20.6%**	**20.7%**	**25.5%**	

Table 35 PhD Student enrolments in All Fields of Education

Source: DEST/DEEWR Aggregated Data Set 'UEAGyyyy' for years 2002 – 2009These are the official figures. Those in Sustaining Science were adjusted for NPS to take account of changes in the classification schemes at Monash that affected the time series. (Compiled by Ian Dobson 2011 for the Physics Decadal Plan Working Group)

Field of Education	2002	2003	2004	2005	2006	2007	2008	2009	Growth - No.	Growth - %
Mathematical Sciences	414	441	475	480	495	503	498	534	120	29.0%
Physical Sciences:										
Physical Sciences - not specified	73	85	95	96	53	54	61	80	7	9.6%
Physics	604	628	658	684	771	788	790	831	227	37.6%
Astronomy	25	38	71	78	88	89	90	78	53	212.0%
Sub-total Physical Sciences	**702**	**751**	**824**	**858**	**912**	**931**	**941**	**989**	**287**	**40.9%**
Chemical Sciences	853	882	926	904	989	1006	1059	1138	285	33.4%
Earth Sciences	629	618	609	527	492	478	480	527	-102	-16.2%
Biological Sciences	2802	2973	3169	2945	3584	3712	3748	3906	1104	39.4%
Other Natural and Physical Sciences#	1153	1219	1314	2420	1932	2047	2004	2069	916	79.4%
Total	**6553**	**6884**	**7317**	**8134**	**8404**	**8677**	**8730**	**9163**	**2610**	**39.8%**
Physical Sciences % of Total	**10.7%**	**10.9%**	**11.3%**	**10.5%**	**10.9%**	**10.7%**	**10.8%**	**10.8%**	**11.0%**	

Table 36 PhD Student Enrolments in Natural and Physical Sciences

Source: DEST/DEEWR Aggregated Data Set 'UEAGyyyy' for years 2002 - 2009
These are the official figures. Those in Sustaining Science were adjusted for NPS to take account of changes in the classification schemes at Monash that affected the time series
Includes courses in '01 Natural and Physical Sciences - General', that universities did not classify more specifically (Compiled by Ian Dobson 2011 for the Physics Decadal Plan Working Group)

Discipline Group	2002	2003	2004	2005	2006	2007	2008	2009	Growth - No.	Growth - %
Overseas Students										
Mathematical Sciences	60	69	73	76	97	115	134	171	110	183.5%
Physical Sciences										
Physics & Astronomy	13	21	17	35	2	3	10	11	-2	-16.0%
Physics	59	66	91	96	124	126	147	175	116	196.7%
Astronomy	6	8	23	27	29	27	23	22	17	307.0%
Sub-total	78	96	131	158	155	156	180	208	131	168.5%
Chemical Sciences	101	103	117	142	184	231	268	296	195	193.1%
Earth Sciences	112	113	122	140	145	162	191	221	109	97.3%
Biological Sciences	306	378	421	486	541	611	702	840	533	174.1%
Other Sciences	112	112	123	127	148	177	179	219	107	96.1%
Total - Overseas Students	**769**	**871**	**987**	**1129**	**1270**	**1452**	**1654**	**1955**	**1186**	**154.2%**
Domestic Students										
Mathematical Sciences	247	271	302	310	314	306	310	302	55	22.2%
Physical Sciences										
Physics & Astronomy	119	104	53	116	8	11	13	15	-104	-87.1%
Physics	298	310	399	358	478	500	504	517	219	73.3%
Astronomy	18	21	26	34	34	35	39	34	17	93.1%
Sub-total	435	434	478	508	520	546	556	566	132	30.2%
Chemical Sciences	564	596	616	618	649	647	676	702	138	24.5%
Earth Sciences	507	518	470	507	366	327	287	283	-224	-44.2%
Biological Sciences	1920	2000	2169	2410	2441	2410	2307	2289	370	19.3%
Other Sciences	516	513	554	546	572	645	631	574	58	11.2%
Total - Domestic Students	**4188**	**4333**	**4587**	**4899**	**4862**	**4881**	**4767**	**4716**	**528**	**12.6%**
All Students										
Mathematical Sciences	308	340	374	386	411	421	444	473	165	53.7%
Physical Sciences										
Physics & Astronomy	132	125	70	151	10	14	23	26	-106	-80.0%
Physics	357	376	490	454	602	626	651	692	335	93.7%
Astronomy	23	29	49	61	63	62	62	57	33	143.7%
Sub-total	512	530	609	666	675	702	736	775	262	51.2%
Chemical Sciences	665	700	733	760	833	878	944	998	333	50.1%
Earth Sciences	619	631	592	647	511	489	478	504	-115	-18.5%
Biological Sciences	2226	2378	2589	2896	2982	3021	3009	3129	903	40.6%
Other Sciences	628	625	677	673	720	822	810	793	165	26.3%
Total - All Students	**4957**	**5204**	**5574**	**6028**	**6132**	**6333**	**6421**	**6671**	**1714**	**34.6%**
Overseas % of All										
Mathematical Sciences	19.6%	20.2%	19.4%	19.7%	23.6%	27.3%	30.2%	36.1%		
Physical Sciences										
Physics & Astronomy	10.0%	16.7%	24.2%	23.2%	20.0%	21.4%	43.5%	41.8%		
Physics	16.5%	17.7%	18.6%	21.1%	20.6%	20.1%	22.6%	25.3%		
Astronomy	23.7%	29.2%	47.1%	44.3%	46.0%	43.5%	37.1%	39.5%		
Sub-total	15.1%	18.1%	21.5%	23.7%	23.0%	22.2%	24.5%	26.9%		
Chemical Sciences	15.2%	14.8%	16.0%	18.7%	22.1%	26.3%	28.4%	29.6%		
Earth Sciences	18.1%	17.9%	20.6%	21.6%	28.4%	33.1%	40.0%	43.9%		
Biological Sciences	13.8%	15.9%	16.2%	16.8%	18.1%	20.2%	23.3%	26.8%		
Other Sciences	17.8%	17.9%	18.2%	18.9%	20.6%	21.5%	22.1%	27.6%		
% - All Students	**15.5%**	**16.7%**	**17.7%**	**18.7%**	**20.7%**	**22.9%**	**25.8%**	**29.3%**		

Table 37 Teaching to students enrolled in PhD courses in Natural and Physical Sciences, by Discipline Group and Citizenship Status

Source: DEST/DEEWR Aggregated Data Set 'UEAGyyyy' for years 2002 – 2009. (Compiled by Ian Dobson 2011 for the Physics Decadal Plan Working Group)

Discipline Group	2002	2003	2004	2005	2006	2007	2008	2009	Growth - No.	Growth - %
Female students										
Mathematical Sciences	82	100	110	127	149	146	144	150	68	83.0%
Physical Sciences										
Physics & Astronomy	38	37	22	41	2	4	7	5	-33	-86.4%
Physics	94	92	110	94	113	122	131	143	49	52.6%
Astronomy	9	13	14	14	15	16	16	18	8	90.1%
Sub-total	141	142	147	149	130	142	154	166	25	17.4%
Chemical Sciences	278	318	326	339	372	372	409	446	168	60.4%
Earth Sciences	213	222	201	193	189	203	194	212	-1	-0.6%
Biological Sciences	1192	1289	1405	1603	1666	1708	1713	1763	571	47.9%
Other Sciences	318	324	346	362	390	455	471	460	142	44.6%
Total - Female	2225	2395	2536	2773	2896	3026	3085	3197	973	43.7%
Male students										
Mathematical Sciences	225	240	265	259	262	275	300	323	97	43.1%
Physical Sciences										
Physics & Astronomy	94	88	47	110	8	10	16	21	-73	-77.4%
Physics	263	284	380	360	489	504	520	548	285	108.4%
Astronomy	14	16	35	47	48	46	46	39	25	179.0%
Sub-total	371	388	462	517	545	560	582	608	238	64.0%
Chemical Sciences	386	382	407	421	461	506	535	551	165	42.7%
Earth Sciences	406	409	390	356	322	286	284	293	-114	-27.9%
Biological Sciences	1034	1089	1184	1293	1316	1313	1296	1366	332	32.1%
Other Sciences	309	302	331	311	330	367	339	333	23	7.5%
Total - Male	2733	2809	3039	3157	3236	3307	3336	3474	741	27.1%
All students										
Mathematical Sciences	308	340	374	386	411	421	444	473	165	53.7%
Physical Sciences										
Physics & Astronomy	132	125	70	151	10	14	23	26	-106	-80.0%
Physics	357	376	490	454	602	626	651	692	335	93.7%
Astronomy	23	29	49	61	63	62	62	57	33	143.7%
Sub-total	512	530	609	666	675	702	736	775	262	51.2%
Chemical Sciences	665	700	733	760	833	878	944	998	333	50.1%
Earth Sciences	619	631	592	549	511	489	478	504	-115	-18.5%
Biological Sciences	2226	2378	2589	2896	2982	3021	3009	3129	903	40.6%
Other Sciences	628	625	677	673	720	822	810	793	165	26.3%
Total - All	**4957**	**5204**	**5574**	**5930**	**6132**	**6333**	**6421**	**6671**	**1714**	**34.6%**

Discipline Group	2002	2003	2004	2005	2006	2007	2008	2009
Female % of All								
Mathematical Sciences	26.7%	29.5%	29.3%	32.9%	36.3%	34.7%	32.4%	31.8%
Physical Sciences								
Physics & Astronomy	29.0%	29.7%	32.2%	27.2%	20.0%	28.6%	30.4%	19.7%
Physics	26.3%	24.5%	22.5%	20.7%	18.8%	19.5%	20.1%	20.7%
Astronomy	39.8%	44.9%	28.9%	23.0%	23.8%	25.8%	25.8%	31.0%
Sub-total	27.6%	26.9%	24.1%	22.4%	19.3%	20.2%	20.9%	21.4%
Chemical Sciences	41.9%	45.4%	44.5%	44.6%	44.7%	42.4%	43.3%	44.7%
Earth Sciences	34.4%	35.2%	34.0%	35.2%	37.0%	41.5%	40.6%	42.0%
Biological Sciences	53.5%	54.2%	54.3%	55.4%	55.9%	56.5%	56.9%	56.3%
Other Sciences	50.7%	51.8%	51.1%	53.8%	54.2%	55.4%	58.1%	58.1%
Total - All	**44.9%**	**46.0%**	**45.5%**	**46.8%**	**47.2%**	**47.8%**	**48.0%**	**47.9%**

Table 38 Teaching to students enrolled in PhD courses in the Natural and Physical Sciences, by Discipline Group and Gender

Source: DEST/DEEWR Aggregated Data Set 'UEAGyyyy' for years 2002 – 2009. (Compiled by Ian Dobson 2011 for the Physics Decadal Plan Working Group)

Field of Education / Citizenship Status	2002	2003	2004	2005	2006	2007	2008	2009	Growth - No.	Growth - %
Mathematical Sciences										
Overseas	13	16	24	15	12	17	24	23	10	76.9%
Domestic	53	69	47	59	66	50	68	52	-1	-1.9%
Sub-total	66	85	71	74	78	67	92	75	9	13.6%
Overseas % of All	19.7%	18.8%	33.8%	20.3%	15.4%	25.4%	26.1%	30.7%	111.1%	
Physical Sciences										
Overseas	19	18	20	18	34	29	34	39	20	105.3%
Domestic	91	121	101	104	90	88	115	112	21	23.1%
Sub-total	110	139	121	122	124	117	149	151	41	37.3%
Overseas % of All	17.3%	12.9%	16.5%	14.8%	27.4%	24.8%	22.8%	25.8%	48.8%	
Chemical Sciences										
Overseas	18	23	19	31	36	38	38	48	30	166.7%
Domestic	152	139	132	121	136	131	129	127	-25	-16.4%
Sub-total	170	162	151	152	172	169	167	175	5	2.9%
Overseas % of All	10.6%	14.2%	12.6%	20.4%	20.9%	22.5%	22.8%	27.4%	600.0%	
Earth Sciences										
Overseas	18	14	18	18	20	17	21	27	9	50.0%
Domestic	59	68	87	82	65	57	46	56	-3	-5.1%
Sub-total	77	82	105	100	85	74	67	83	6	7.8%
Overseas % of All	23.4%	17.1%	17.1%	18.0%	23.5%	23.0%	31.3%	32.5%	150.0%	
Biological Sciences										
Overseas	71	83	87	68	86	113	96	112	41	57.7%
Domestic	400	468	447	411	450	456	499	474	74	18.5%
Sub-total	471	551	534	479	536	569	595	586	115	24.4%
Overseas % of All	15.1%	15.1%	16.3%	14.2%	16.0%	19.9%	16.1%	19.1%	35.7%	
Other Natural and Physical Sciences										
Overseas	27	31	54	55	60	76	59	75	48	177.8%
Domestic	141	156	195	274	233	297	239	243	102	72.3%
Sub-total	168	187	249	329	293	373	298	318	150	89.3%
Overseas % of All	16.1%	16.6%	21.7%	16.7%	20.5%	20.4%	19.8%	23.6%	32.0%	
All Natural & Physical Sciences FoEs										
Overseas	166	185	222	205	248	290	272	324	158	95.2%
Domestic	896	1021	1009	1051	1040	1079	1096	1064	168	18.8%
Total	**1062**	**1206**	**1231**	**1256**	**1288**	**1369**	**1368**	**1388**	**326**	**30.7%**
Overseas % of All	15.6%	15.3%	18.0%	16.3%	19.3%	21.2%	19.9%	23.3%	48.5%	

Table 39 Course completions: Natural and Physical Sciences Students – PhDs by Citizenship Status

Source: DEST/DEEWR Aggregated Data Set 'UEAGyyyy' for years 2002 – 2009. (Compiled by Ian Dobson 2011 for the Physics Decadal Plan Working Group)

PHYSICS RESEARCH AND FUNDING

Key points

- Physics is an enabling discipline; assigning the contribution of an Individual's physics training to the nation's research productivity is not possible, and will undervalue the role of physics.
- Physics research at Australian Universities is well ranked in a global context.
- ERA assessments have a significant lag time, but using ERA ratings, Australian University physics research is a national research strength.
- Although physics research quality is a strength, commercialisation from this research is a weakness. This is a national trend across other disciplines.
- The amount of funding secured by physics research projects in universities is comparable to the level of measured research outcomes; however, physics is relatively over-represented in ARC funded projects.
- Gender inequality in physics research funding is impossible to substantiate but providing support to female professionals may reflect an opportunity for future growth in physics.
- The ARC Centre of excellence scheme was well suited to the physics research community, and physics research funding has significantly benefited from this scheme.
- Several large government service agencies are major employers of physicists, but accurate data are not available.
- Across the physic sub-disciplines, there are numerous examples of Australian teams that are making significant contributions to discovery and innovation as well as contributing to the global research effort through collaboration.

Australia has a vibrant physics research community. There are a number of major sub-sectors in the physics research sector:

- Higher Education Institutions such as universities,
- CSIRO
- DSTO
- ANSTO
- The Bureau of Meteorology
- CRCs
- Centres of Excellence
- NICTA
- Research Institutes affiliated with or part of any of the above entities.

All of these sub-sectors are involved in the whole spectrum of research from fundamental to applied research and all are involved in national and international collaborations, knowledge and technology transfer and commercialisation.

Most of the government funded agencies are involved in research and development with a focus on the more applied end of research and have, as part of their remit, the purpose of interacting with and delivering benefits to industry. All of these agencies also provide advice to other government agencies, government ministers and industry clients.

To clearly identify and separate out the number of physicists working in each one of these entities without double-counting would require in-depth research, particularly as physicists in the non-university segment are not employed as 'physicists' but in a specific research and development role. For example, a research scientist in a CSIRO flagship position may be employed as a Science Leader in Composite Materials, a physicist in the Bureau of Meteorology may be working in the role or position of meteorologist. Most of these organisations do not keep a specific data file on the number of physicists employed. For these reasons, apart from the university sub-segment, only estimations can be provided about the number of physicists working in research roles in these organisations.

It is equally difficult to attribute research outputs such as scientific publications to physicists in most of these organisations, apart from universities, and therefore provide solid numbers on the scientific or intellectual property output of physics as a discipline in Australia.

Similarly, as non-university research organisations are typically not ranked in global ranking tables on research excellence, research output and impact criteria, it is very difficult to conduct a comparative review of physics in the non-university research sub-sectors.

Universities

Ranking of Australian physics in world tables

Research in the physical sciences contributes substantially to the global rankings of Australian universities. Depending on the ranking agency, the rankings of specific universities vary by a number of places. However, in general, the University of Melbourne and the Australian National University (ANU) have been the two highest ranking universities over a number of years. For example, on the ARWU top science rankings in 2010, ANU ranked at place 40 and the University of Melbourne at 44. The same ranking agency in the Physics ranking tables, place ANU at rank 59, the University of Melbourne at 62 and the University of Sydney at 92. In the 2010 Times Higher Education rankings, in Physics only, the University of Melbourne and the ANU rank in the top 100 universities, the University of Melbourne at rank 28, the ANU at 24. The newest 2011 QS rankings for physics and astronomy list the University of Melbourne at place 14, the ANU at place 28, Monash University, the University of NSW and the University of Sydney are in the 50 to 100 ranking band, and the Universities of Queensland, Adelaide and RMIT University are ranked between 150 and 200[63]. Although this is clearly above world average, based on these ranking tables it is clear that Australian physics can be defined as world competitive, but not world leading, as the top US and European universities maintain their placing at the top of the ranking tables. Most of the universities in the major Asian economies are consistently improving in their ranking and in the future will provide competition to the established universities and physics faculties in Australia.

Physics research excellence rankings (ERA)

There were 24 universities that were assessed in the 2010 ERA research excellence assessment. As the results of this assessment depend on data *in part* selectively provided by the universities, and given that some expectation regarding the impact of the data on future funding was likely, the ERA ratings need to be interpreted cautiously given that maximisation strategies were possible.

[63] http://www.topuniversities.com/university-rankings/world-university-rankings/2011/subject-rankings/natural-sciences/physics

The ERA ratings do not give a picture of the excellence of the research *currently* conducted in universities as the assessed research outputs and impact indicators are based on research initiated and resourced five or more years previously. For example, research outputs published at the beginning of the ERA reference period would have been completed well before that to successfully pass through the scientific journal refereeing, editing and publishing process. Esteem indicators, patents and research commercialisation income have an even longer lag time.

Therefore, the ERA 2010 results should be interpreted mainly as indicators of research excellence in the 10 years prior to the release of the results and they should be used, in the context of this report, merely as a baseline for setting targets for the implementation of strategic and tactical changes in research funding and management for the next decade and beyond. As the assessment criteria for subsequent ERA assessment will change over time, it is not likely that comparisons can be easily made in the future between years and universities. Nevertheless, according to ERA 2010, physics showed above world average performance in research output.

The physical sciences (FoR code 02) accounted for approximately 4% of the national research output from Australian universities and received approximately 4% of Australian government competitive grants income. The majority of these outputs were journal articles, with 13,666 in total over the six year assessment period. The largest sub-disciplines were astronomical and space sciences with 3,374 and optical sciences with 3,067 research outputs, this was followed by atomic, molecular, particle and plasma physics with 2,746, and condensed matter physics with 2,425 research outputs (Table 40).

The average national rating for Australian Physics was 3.8 on a scale of 5 rating. Eighty-six per cent (86%) of the 24 assessed research institutions in physical sciences received a rating at or above world average standard. Physics rated third out of all the 2 digit code disciplines behind technology (5.0 – for which only 1 institution provided assessable data) and earth sciences (3.9 from 21 institutions). In addition, the two physics sub-disciplines mathematical physics (0105) and geophysics (0404) which were counted under mathematics (01) and earth sciences, (04) showed above world average scores of 4.5 and 3.4 respectively.

Based on the 2010 ERA assessment criteria, university based physics research is clearly, therefore, a national research strength. Further, given the role of physics as an enabling discipline, much of physics research contributes to outputs in other disciplines, so its full impact is much greater than the raw physics data contained in ERA might suggest.

Discipline	Average rating*	Assessed units of evaluation	FTEs	Research Outputs
Physical Sciences	3.7	24	965	13,666
Astronomical & Space Sciences	4.2	13	204	3,374
Atomic, Molecular, Nuclear, Particle & Plasma Physics	2.9	11	152	2,746
Classical Physics	5.0	1	33	441
Condensed Matter Physics	3.5	15	196	2,425
Optical Physics	4.0	12	189	3,067
Quantum Physics	4.5	8	62	837
Other Physical Sciences	3.6	5	130	776
Mathematical Physics	4.5	6	60	688
Geophysics	3.4	9	78	1,023

Table 40 ERA 2010 ratings, Full Time Equivalents (FTEs) and research outputs

* Lowest = 0, Highest = 5; World standard = 3

Discipline	Research Income ($)	Esteem Outputs	Commercialisation Income ($)	Patents sealed
Physical Sciences	203,346,670	192	7,241,615	31.0
Astronomical & Space Sciences	30,102,688	31	1,102	--
Atomic, Molecular, Nuclear, Particle & Plasma Physics	28,415,537	29	58,063	--
Classical Physics	3,936,524	6	--	3.8
Condensed Matter Physics	44,050,228	37	2,584,472	6.8
Optical Physics	45,644,092	45	5,216,985	13.9
Quantum Physics	26,010,277	24	79,423	2.0
Other Physical Sciences	25,187,323	19	301,570	2.2
Mathematical Physics	15,735,489	10	--	--
Geophysics	28,679,038	10	51,150	0.5

Table 41 ERA 2010 Research income and Impact measures

In terms of research quality measures such as relative citation impact, research income and esteem outputs Australian university based physics ranks highly, however, the commercial impact metrics do not reflect a substantial impact of university based research in terms of patents sealed and commercialisation income received via royalties or other translation into technology based income (Table 41). This supports evidence provided in other sections of this report on the Australian innovation track record.

University competitive grant income

The university based physics (02) competitive grant income, based on the ERA 2010 assessment period from 2006 to 2008 was $136,263,146 million, varying between $44.1 million and $46.4 million per year. Other public sector income in the same time period added another $35.3 million and industry and other national and international research income added $52.2 million (Table 42). Income from CRCs was comparatively low over the three years with a total of 5.1 million.

Discipline	Competitive grant income ($ million)	Industry and other national and international other ($ million)	CRC income ($ million)	Commercialisation income ($ million)
Physics (02)	136.26	53.30	5.10	7.24
Geophysics	5.10	31.10	2.40	0.12
Mathematical Physics	9.41	19.81	0.37	0.00
Total	150.77	104.21	7.87	7.36

Table 42 Research funding via different university research income types during the three year period 2006 to 2008, according to ERA 2010

Research funding and the ARC

The main source of competitive grant income for the higher education and research sector is the Australian Research Council (ARC).

A complete set of data, covering the last decade from 2001 to 2011, related to the funding to physical sciences, mathematical physics and geophysics by primary classification code and gender of lead investigator has been provided by the ARC (Appendix 10).

A change in primary classification code systems within the reporting period of 2002 to 2011, makes summarising the ARC data difficult. Mathematical physics, which may have been included in theoretical and condensed matter physics before 2009, is now coded under mathematics. Similarly, before 2009, geophysics was coded under physics and is now coded under earth sciences. The year with overlapping codes was 2010.

Summarising geophysics, mathematical physics and the physical sciences together, the ARC from 2001/2002 to 2010/2011, funded 1067 research projects worth $598.86 million (Table 43). This amounts to 11.8% of the ARC's funds during the reporting decade[64].

Discipline	Number of ARC projects for commencement from 2002 to 2011	Funding for ARC projects for commencement from 2002 to 2011 ($ million)
Astronomical Sciences, Astronomical and Space Sciences	239	132.96
Theoretical and Condensed Matter Physics, Condensed Matter Physics. Mathematical Physics, Quantum Physics	261	169.43
Optical Physics	206	111.53
Atomic, molecular, nuclear, particle and plasma physics	153	104.78
Other Physical Sciences	116	54.83
Geophysics	61	13.51
Classical Physics	31	11.82
Total	**1067**	**598.86**

Table 43 Number of ARC funded Physics research projects and funding allocation for the ten-year period from 2002 to 2011

Overall, the physics disciplines were very successful in attracting competitive ARC funding and they experienced relative consistency in funding levels from year to year (Table 44). Peaks in funding were predominantly due to the commencement of new ARC Centres of Excellence. An example of such a peak is the year 2011. A similar peak occurred in the year 2002/2003.

Year	2001/02	2002/03	2003/04	2004/05	2005/06	2006/07	2007/08	2008/09	2009/10	20010/11
ARC funds in $ '000	277	369	426	495	572	585	589	622	692	752
Physics $ in'000	38.3	70.8	44.3	49.4	39.4	45.6	50.4	48.1	61.9	154.8
% captured by Physics	13.8	19.2	10.4	10.0	6.8	7.8	8.6	7.7	8.9	20.5

Table 44 ARC funds captured by physics

The physics funding is tracking CPI increase quite steadily, with a peak in 2011 (Figures 14 and 15). The changes are more structurally, with a larger fraction coming from the more recent excellence schemes, such as Centres of Excellence, Fed Fellows and more recently Laureate and Future Fellows scvhemes. Physics has benefited from these schemes. In comparison the DP grants are less predominant and there are very few Linkage grants in physics. This may be due to the fact that physics research operates at the very fundamental research end of

[64] http://www.arc.gov.au/pdf/annual_report_10_11.pdf

the innovation spectrum and application is seen as too far away from commercial application and therefore investment into a research partnership is seen as too risky by industry linkage partners.

Total ARC funding is tracking CPI. The ARC funding peaked in 2007 and is now remarkably stable. An increase would be required to make up for increased costs. Overall, as for physics, funding has moved from the DP grants to the excellence grants.

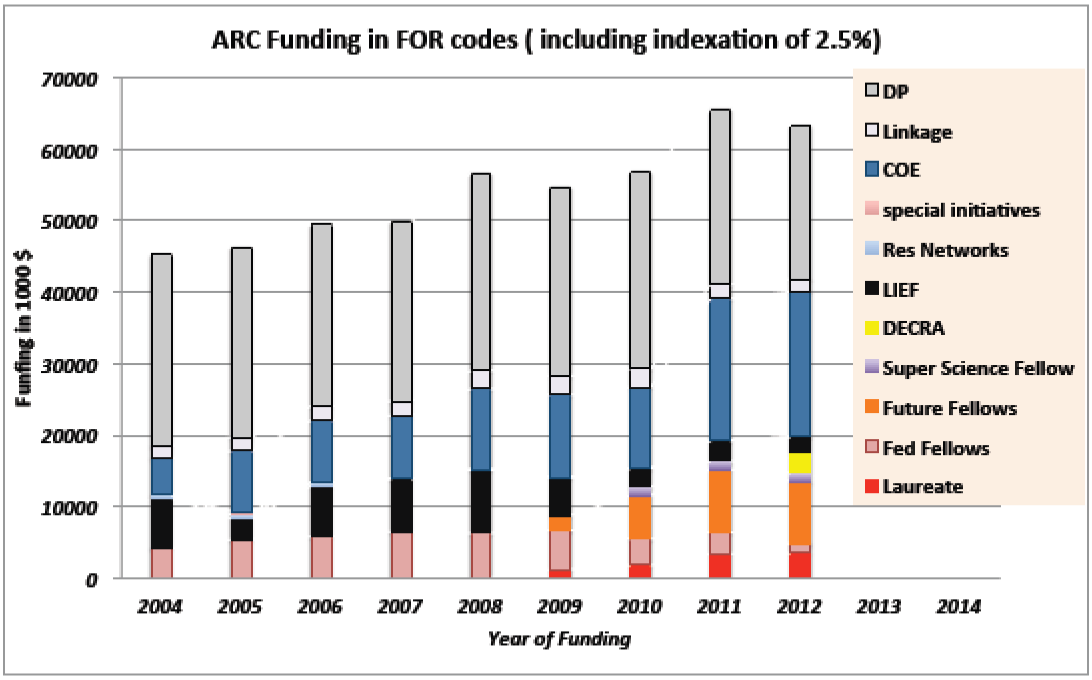


Figure 14 ARC funding for physics, indexed to CPI. (Source Hans Bachor, ANU)

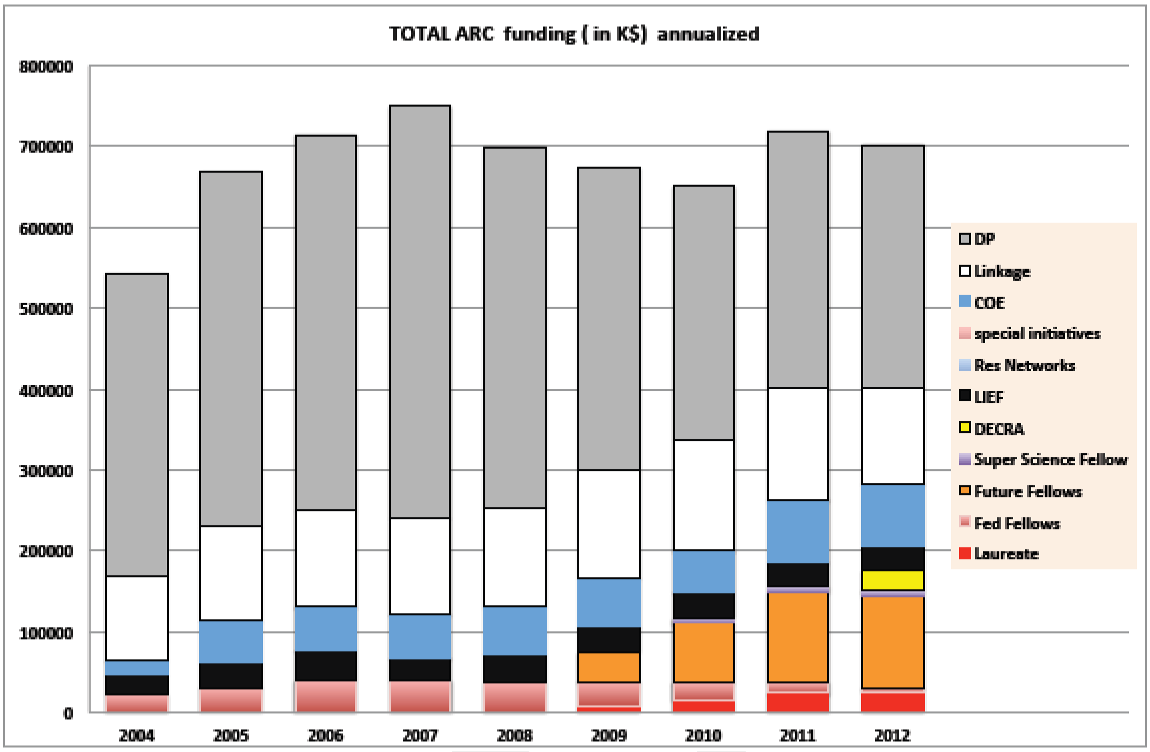


Figure 15 Total ARC funding annualised. (Source Hans Bachor, ANU)

Success rates for proposals and gender equity in ARC funding

Success rates for proposals in the area of physics were similar to those in other disciplines. Over the last 10 years the overall success rate across all funding schemes within ARC has demonstrated a downwards trend after a relatively stable range of success rates of between 33.0% and 35.9% from 2001 to 2003. Since then, the success rate has dropped as low as 22.4% and only once, in 2007, reached 30%. As the ARC funding process mostly provides only partial funding for a research project, generally only 50%, the success rate at full funding would likely drop to well below 20% or in some schemes even below 10%, thus making the application process even more inefficient.

The ARC has a number of funding schemes and the fiercest competition for funding is for discovery project grants and for ARC fellowships. The success rate for discovery grant applications for the physics sub-disciplines in this scheme has reached 30% only once in the last ten years and has, since 2006, been hovering between 19% and 23%.

The number of applications across all schemes has been steady rising over the years, from 294 in 2001/02 to 408 in 2010/11. Specific schemes attract large numbers of applications, for example the discovery projects and the recently commenced Discovery Early Career Researcher Award (DECRA). The physics sub-disciplines have been very successful in attracting a number of these new 2012 DECRA Awards. With $9.35 million of the $19.125 million allocated through the PCE panel, 49% of these funds were captured by physics and geophysics.[65] (Table 45).

[65] http://www.arc.gov.au/pdf/DECRA12/Successful_Proposals_by_FoR.pdf

Panel*	Proposals considered	% of proposals considered	Proposals approved	Success rate	Allocated funds (over project life)
BSB	499	23%	70	14.0%	$26,250,000
EMI	503	23%	57	11.3%	$21,375,000
HCA	367	17%	45	12.3%	$16,875,000
PCE	404	19%	51	12.6%	$19,125,000
SBE	386	18%	54	14.0%	$20,250,000
Total	**2159**	**100%**	**277**	**12.8%**	**$103,875,000**

*(BSB – Biological Sciences and Biotechnology; EMI – Engineering, Mathematics and Informatics; PCE – Physics, Chemistry and Earth Sciences; SBE – Social, Behavioural and Economic Sciences; HCA – Humanities and Creative Arts)

Table 45 Numbers and success rates for ARC Discovery Early Career Researcher Award proposals for funding commencing in 2012, by Disciplines

The proportion of female lead investigators in submissions across all schemes varies from year to year, ranging between 8.8% and 14.8% over the last 10 years with no clear trend upwards or downwards. The proportion of female lead investigators within each year has been between 10.2 and 14.3% of funded projects. However, the success rate for discovery project proposals from women has only been larger than for men in three years out of the ten years from 2001 to 2010, in the years 2003 by 5.3%, 2005 by 5.6% and 2010 by 0.7%. In all other years the success rate for males exceeded the rate for females, in four years by 0.7 to 5.3% and in three years by 8.1%, 10.3 and 11.2%.

Overall, the number of female fellowship holders in all schemes is lower than male fellowship holders. Not only were the number of applications submitted by women lower in these categories, their success rate was also much lower, with the exception of the Federation Fellowships where four out of 9 women were awarded a fellowship over the seven years of the scheme (Table 46). The fellowship schemes that fund more junior fellowship positions such as postdoctoral fellows and Australian Research Fellows, appear to have a comparatively higher proportion of successful female applicants (17% to 25%) than the higher level schemes such as Future Fellowships, Australian Laureate Fellowships and Federation Fellowships where the success rate of women overall is much lower. In these schemes the female applicant proportion of the fellowship scheme has been very low and over the reporting period was 3% for Australian Laureate Fellowships, 5% for the Federation Fellowships and 12% for the Future Fellowships.

Specific funding issues

Although most of physics research is laboratory based, larger research infrastructure is constantly under the threat of support staff and maintenance budgets not being able to be kept up to standard required to ensure that these instruments and related infrastructure are operable and available for the national and international research community. Similarly, budgets for subsequent upgrades are often not included in the planning stages for large infrastructure.

This jeopardises the ability of Australian physics research to remain at the cutting edge of research and international collaboration.

Fellowship scheme	Applications by men	Success rate of men (%)	Applications by women	Success rate of women
Australian Laureate Fellowship (2 years)	37	8.1	1	0
Federation Fellowships (7 years)	163	14.7	9	44.4
Future Fellowships (3 years)	127	32.3	17	11.8

Table 46 Competition in the ARC senior fellowship schemes

Over the reporting period from 2002 to 2010, 24 male and only four female Federation Fellows were appointed, three male and no female Australian Laureate Fellows, and 41 male and two female Future Fellows; of 30 appointed Professorial Fellows only one was female.

Both low application rates and lower success rates for female research physicists, especially at the high end of the fellowship schemes, portray a current gender imbalance and the existence of a "glass ceiling" in physics departments in the university environment.

The only schemes in which there seems to be a more even gender balance are the Linkage schemes. The Super Science Fellowships portray a more balanced picture with a 60/40% split in the success rate of males over females, but, as some of the applications did not specify gender, it is difficult to clearly interpret the numbers.

Overall, it is very difficult to clearly demonstrate and statistically prove disadvantages to women applying for funding within the ARC funding schemes due to their low numbers in the university system and especially due to their low numbers as applicants in the different ARC funding schemes. However, the low application rates of women may indicate that they may either expect a low success rate due to gender bias or they make conscious trade-offs in terms of time spent on research and on writing applications, and instead become co-investigators rather than lead investigators.

Downstream impact of university-based research

The impact of Australian university based research can be interpreted from the ERA 2010 research impact indicators, esteem outputs, commercialisation income and patents sealed. The ERA reporting period for these impact indicators was three years (2006 to 2009).

Esteem indicators have impact on the potential for capturing research funding income nationally and internationally from both government and industry, and by establishing national and international collaborations they also have an influence on the image that Australian physics portrays to international students.

Patents are a lag indicator and the number of patent applications filed and sealed depends on much more than the excellence of the research of the patent author, namely university patent and commercialisation strategies and commercial inclination and skills of the physics departments and their scientists in commercialisation processes.

Overall, the physical sciences (02), not including geophysics and mathematical physics, rank high on esteem indicator scale, high on the patent scale and very low on the commercial income impact indicator scale. The most productive sub-discipline of the physical sciences was optical physics, which is not surprising, followed by condensed matter physics and classical physics. Both astronomical and space sciences, and atomic, molecular, particle and plasma physics did not seal any patents over the three year reporting period.

Given that the only triadic patent of all disciplines assessed in ERA 2010 originated in classical physics, this can be seen as an achievement for the physical sciences.

Commercial income derived from commercialising intellectual property (IP) lags even further behind the patents impact indicator. This indicator shows that very little income has been received over the reporting period.

Centres of excellence, institutes and research centres

There are a multitude of institutes, centres and other entities within each university that try to portray to the national and international general public an image of focus around a research group. Some of these institutes and centres are very small, and it is doubtful that any in-depth analysis of these entities would add value to this report as most of them are internal to science schools or physics or engineering departments and are therefore already analysed within the university and ERA 2010 context.

However, the ARC Centres of Excellence program has been very successful in terms of providing critical mass and funding for specific physics areas and has a large impact on Australia's capabilities in physics research. Indeed, it can be said that the Centres of Excellence scheme is an ideal mechanism for enhancing research capacity in physics, which traditionally benefits from close interaction between theory and experiment, and between complementary, medium-scale experimental facilities. This is reflected by the high demand for, and the high success rates in, physics-based Centres of Excellence (Table 47).

The ARC Centre of Excellence scheme provided a significant boost to research activities involving physics in Australia. Of the 17 centres funded in the 2002 round for commencement in 2003, seven involved personnel from physics or people who had physics qualifications. Most of these centres involved large teams working on programs which included some aspect of physics. Similar records were achieved in 2005 (4 out of 11) and 2011 (5 out of 13). Clearly, the strong international focus of physics research, the productivity that comes from collaboration between theorists and experimentalists and the ability of teams to unite with a clear focus to address significant problems that span the innovation continuum is well matched to the goal of program to "undertake highly innovative and potentially transformational research that aims to achieve international standing in the fields of research envisaged and leads to a significant advancement of capabilities and knowledge"[66]. Classification of this activity against the traditional disciplines presents challenges and represents a trend away from a narrow discipline focus. A future decadal plan for physics will need to evaluate how to incorporate the interdisciplinary research conducted within centres and other interdisciplinary enterprises.

[66] http://www.arc.gov.au/ncgp/ce/ce_default.htm

2003 Commencement[67]	Lead Institution	Start Year	End Year
ARC Centre of Excellence for Advanced Silicon Photovoltaics and Photonics	UNSW	2003	2010
ARC Centre of Excellence for Quantum-Atom Optics	ANU	2003	2010
ARC Centre of Excellence for Quantum Computer Technology	UNSW	2003	2010
ARC Centre of Excellence for Ultrahigh-bandwidth Devices for Optical Systems	USyd	2003	2010
ARC Centre for Solar Energy Systems	ANU	2003	2007
ARC Centre for Functional Nanomaterials	UQ	2003	2007
ARC Centre for Nanostructured Electromaterials	U Wollongong	2003	2005
2005 commencement[68]	**Lead Institution**	**Start Year**	**End Year**
ARC Centre of Excellence in Design in Light Metals	Monash U	2005	2013
ARC Centre of Excellence in Antimatter-Matter Studies	ANU	2003	2013
ARC Centre of Excellence in Coherent X-ray Science	U Melbourne	2005	2013
ARC Centre of Excellence for Electromaterials Science	U Wollongong	2005	2013
2011 commencement[69]	**Lead Institution**	**Start Year**	**End Year**
ARC Centre of Excellence for All-sky Astrophysics	U Sydney	2011	2017
ARC Centre of Excellence for Engineered Quantum Systems	UQ	2011	2017
ARC Centre of Excellence for Particle Physics at the Tera-Scale	U Melbourne	2011	2017
ARC Centre of Excellence for Quantum Computation and Communication Technology	UNSW	2011	2017
ARC Centre of Excellence for Ultrahigh Bandwidth Devices for Optical Systems	U Sydney	2011	2017

Table 47 ARC Centres of Excellence with Physics involvement

CSIRO

CSIRO employs about 6500 staff and has a budget of over $1billion. It undertakes mission oriented research. Traditional physics has been diminishing in size and visibility in CSIRO over the last 10 years. However, physics is integrated fully across the organisation with a concentration of physicists in the CSIRO divisions of materials science and engineering, space and astronomy, and geosciences. The main sectors that physics research is used for is in manufacturing, mineral exploration and mining, telecommunications, health, and in environmental monitoring. CSIRO is not able to provide data on the specific number of physicists it employs but estimates about 500 researchers. CSIRO has few women in the senior levels of the organisation (Figure 16).

[67] http://www.arc.gov.au/ncgp/ce/2003_coe_funding.htm
[68] http://www.arc.gov.au/ncgp/ce/2005_coe_funding.htm
[69] http://www.arc.gov.au/ncgp/ce/2011_coe_funding.htm

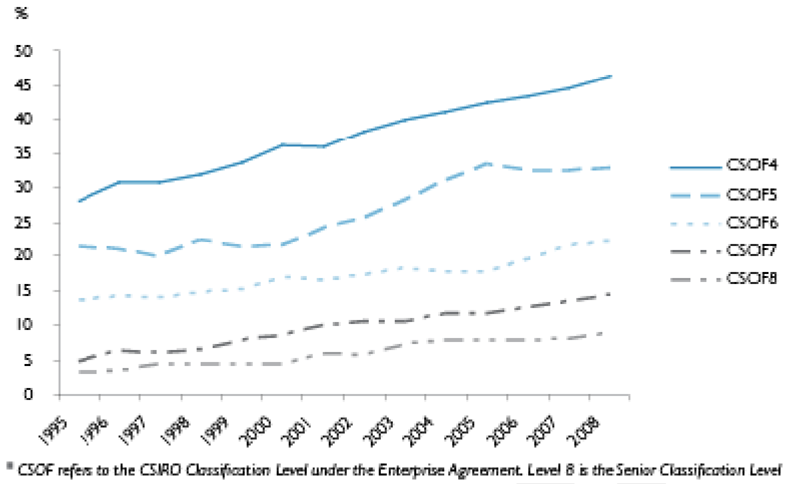


Figure 16 Percentage of Females by CSOF level 1995 - 2008

Source: CSIRO Annual Report 07/08

Defence Science and Technology Organisation (DSTO)

The DSTO is the Australian government's lead agency charged with applying science and technology to protect and defend Australia and its national interests. DSTO delivers expert, impartial advice and innovative solutions for defence and other elements of national security.

Headed by the Chief Defence Scientist, DSTO has an annual budget of approximately $400 million and employs around 2,500 staff, predominantly scientists, engineers, IT specialists and technicians. According to DSTO Human Resources, the last census of staff professional backgrounds was undertaken in 2007/08 and at that time there were 195 people with a physics background. With a current number of 2500 staff one could expect at least 200 to 400 staff with a physics background working in DSTO. No data on gender equity of physicists are available for this research organisation.

DSTO has a transparent career structure with flex-time, transparent set pay brackets and reasonable working hours which were mentioned as a positive for women/parents during the consultation process for this report.

The research focus is on applied research and the research breakthroughs of the DSTO Achievers each year from 1988 to 2009 reflect that research focus.

Australian Nuclear Science and Technology Organisation (ANSTO)

ANSTO is Australia’s national nuclear research and development organisation and is the centre of Australian nuclear expertise. It is part of the Australian Government portfolio of Innovation, Industry, Science and Research. ANSTO undertakes research in the applications of nuclear science and technology and delivers specialised advice, scientific services and products to government, universities, other research organisations, international organisations and businesses in areas as diverse as mining and radiopharmaceuticals. About one-third of ANSTO’s staff is involved in research. The balance is in business services, operations and support to government roles. ANSTO operates Australia’s nuclear research reactor OPAL which is used to produce radioactive products for use in medicine and industry, as a source of neutron beams for scientific research and to irradiate silicon for semiconductor applications. ANSTO’s research infrastructure also includes accelerators, cyclotrons and associated instruments as well as workshops, pilot plants and specialist laboratories. ANSTO's research infrastructure is used extensively by other members of the Australian and international research communities including researchers from universities, other science and technology organisations and industry. ANSTO also manages the Access to Major Research Facilities Program (AMRFP), which provides Australian researchers with access to major international facilities. ANSTO's main campus is located 40 km south west of Sydney's central business district, occupies 70 hectares and is surrounded by a 1.6 km buffer zone. The organisation's functions are prescribed by the Australian Nuclear Science and Technology Organisation Act 1987 (ANSTO Act) and are translated into action through its strategic and annual planning process.

The ANSTO annual report 2008-2009[70] lists performance in 2007-2008 and 2008-2009 in terms of some of the ERA 2010 type indicators (Table 48).

Indicator	2007-2008	2008-2009
Publications (journal articles and book chapters)	262	282
Invention disclosures	7	6
Provisional patent filings	3	0
Number of postgraduates supervised	100	81
Revenue from government	$173.115m	$173.115m
Revenue from goods and services	$44.667m	$44.004m
Grant income	$1.916m	$1.906m
People employed male	739 (72%)	676 (73%)
People employed female	289 (28%)	250 (27%)

Table 48 ANSTO performance indicators 2007/08 to 2008/09

As approximately one third of the ANSTO is involved in science, a substantial number of ANSTO employees are most likely physicists. However, it can be expected that many of the ANSTO staff not involved in science and research but in business and advisory roles to government would also hold a Bachelor of Science degree with a major in physics.

Cooperative Research Centres (CRCs)

There are 42 different CRCs currently being funded, of which 17 require physics capability as an enabling science. There is no specific data on the number of physicists employed. An example is the CRC for Welded Structures based in Wollongong. Welding is one of the most commonly used manufacturing processes. It is essential for the fabrication of a wide range of products from the micro-circuits used in computers to aircraft engines, super tanker hulls, bridges and buildings. Even the exploitation of Australia's rich mineral reserves depends on welding for the construction and maintenance of mining equipment and infrastructure. Progress in welding technology is made possible by process developments which improve productivity and reduce costs, and these developments are underpinned by a thorough understanding of the physics of the processes.

[70] ANSTO Annual Report 2008-2009. 2009

Government service agencies

Health care providers

Health care providers such as hospitals provide diagnostic and therapeutic services such as medical imaging and radiotherapy and in these services employ physicists and medical physicists. Medical physicists undergo further specialised training after achieving their Bachelor of Science degree in physics.

A 2009 employment survey by ACPSEM, the professional organisation overseeing professional development and accreditation of medical physicists showed that there were

341 individual positions in radiation oncology,
67 individual positions in radiology physics,
71 individual positions in nuclear medicine physics,
171 individual positions in biomedical engineering,
29 positions attributed to ‘other’.

The total number of physicists in medical physics is estimated to be around 500 to 600, a similar number to those working in the academic sector or at CSIRO or DSTO.

There was a 25%growth in the radiation oncology workforce in the three years from 2006 to 2009 and a 22% growth in radiology physics. There are, however, not enough positions made available for imaging physicists, despite the increase in imaging infrastructure in hospitals.

Bureau of Meteorology (BOM)

The BOM employs a fairly large number of scientists with a physics background. However, detailed numbers are not available as new recruits are employed to fulfil specific roles such as modelling or as meteorologists after receiving specific training in this subject. It is estimated that the BOM employs around 90 people with a physics background.

The research spectrum of the BOM spans fundamental to applied research. The BOM works in partnership with the CSIRO in a number of facilities in a number of important areas of climate research, ocean monitoring and the analysis of the composition of the atmosphere. There are three major research entities:

- The Centre for Australian Weather and Climate Research which includes the Joint Australian Facility for Ocean Observing Systems
- Baseline Air Pollution Station
- High Performance Computing and Communication Centre,

One of the unique research programs relates to tropical climate research, as Australia is one of the very few countries with a tropical climate and the high powered facilities and skills to conduct research in this field.

The National Measurement Institute (NMI)

The NMI is the peak Australian measurement body responsible for biological, chemical, legal, physical and trade measurement.

It is responsible for the development and maintenance of standards of measurement, reference materials and reference techniques to meet the measurement needs of government, industry and scientific organisations for calibration, analysis and training.

According to the NMI website[71] , the organisation is responsible for the delivery and maintenance of capability for measurement in Australia that is world class, increases national economic efficiency, enhances export trade prospects, empowers sound environmental regulation, and enables effective social and health policies.

It aims to maintain Australia's measurement standards, provide national leadership in measurement science, lead global collaboration, improve and develop services, grow research and development capability, and implement the national trade measurement system.

On 1 July 2010, NMI became responsible for trade measurement. NMI is now responsible for the full spectrum of measurement, from the peak primary standards of measurement to measurements made at the domestic trade level.

The Australian Bureau of Statistics (ABS)

The ABS is the central statistical authority for the Australian Government and, by arrangements with the governments of the states, provides statistical services for those governments also. It provides statistics on a wide range of economic, social, population and environmental matters, covering government, business and the community. It also has an important coordination function with respect to the statistical activities of other official bodies, both in Australia and overseas.

The ABS employs substantial numbers of mathematicians and physicists in modelling, analytical and statistical service functions. In 2010, the ABS employed 3289 staff and runs a graduate employment program. The number of physicists employed by the ABS is unknown.

Other service agencies

Other service agencies employing physicists include:

- Air Services Australia, a government owned company for air traffic management, aviation rescue and fire fighting services, the provision of aeronautical data, telecommunications and navigation services. Air Services Australia employs 3700 staff and amongst them also physicists in modelling and other functions.
- State Departments of Health for modelling and predictions on population health issues and developing policy.
- The Defence Signals Directorate, an intelligence agency of the Department of Defence for collecting and analysing foreign signals intelligence and for providing information security advice for federal and state government agencies and to industry to develop and deploy secure cryptographic products.
- Federal and State government departments use data for modelling and for strategy and policy development. Due to their expertise in problem solving and mathematics physicists are employed in analytical and advisory positions in treasury, defence departments and strategic planning offices of various ministers. It is not known how many physicists work in such positions.

[71] http://www.measurement.gov.au/Pages/about.aspx

Current physics research focus and global competitiveness

The following section provides a summary of the activities which are taking place within the various physics sub-disciplines. A full report on the activities within the different sub-discipline clusters can be found in Appendix 8.

Cluster 1: Materials, energy and computing

This cluster includes the following fields:

- Condensed matter and materials physics
- Energy and power technologies
- Chemical physics
- Supercomputing

By international standards, Australia has strengths across the innovation spectrum in condensed matter and materials physics. They range from curiosity-driven research in fundamental quantum mechanics and materials science, all the way to the applied science and engineering of silicon photovoltaic (PV) systems. The ability of Australian scientists, through schemes such as the ARC's Centres of Excellence, to form large teams which collaborate on research programs enables a greater impact than would be possible with independent groups.

The field is supported by substantial infrastructure within universities and the CSIRO and includes several large facilities such as the OPAL reactor[72], the Australian Synchrotron[73], the Australian Microscopy and Microanalysis Research Facility[74], and the Australian National Fabrication Facility[75].

The continuing reappraisal of quantum mechanics for its application to technological devices will remain a strong theme for Australian researchers. Emerging themes at the boundary of physics and biology are already evident today and are likely to be even more significant in the future. This is aligned with major international trends sometimes described as "convergence" as in the American Association for the Advancement of Science Study[76]. The impact of the new supercomputer facilities is also likely to be significant in the future as researchers seek more accurate models for physical systems at the atomic, molecular and integrated device levels. The global imperative to address issues in climate science is likely to see larger research programs established to study materials for alternative power and energy efficiency, alongside the programs in silicon PV, which are already large.

Current research focus and global competitiveness

Condensed matter and materials physics: Within Australia there are many interdisciplinary research programs investigating new materials. And the challenges are still great and interesting even in the most widely studied system, silicon. The rise in activity in the field of quantum information and communication in Australia has driven research programs into relevant materials. These have led to the emergence of large, coordinated programs within the Australian Research Council (ARC) Centres of Excellence scheme. New challenges are arising from the use of materials with strained layer lattices, and from understanding defects in semiconductors. An example is the emergence of "III-V" materials—compounds, like gallium arsenide, which include an element from Group III and an element from Group V in the Periodic Table. They have applications to photovoltaics (PV), and this is supported by the introduction of new ion implantation machines. Nano-indentation-based phase-change memories, and resistive memories based on dielectric films are other

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[72] http://www.ansto.gov.au/discovering_ansto/anstos_research_reactor
[73] http://www.synchrotron.org.au/
[74] http://www.ammrf.org.au/
[75] http://anff.org.au/index.html
[76] http://web.mit.edu/newsoffice/2011/convergence-0104.html

emerging areas of research. III-V semiconductor-based quantum well and quantum dot optoelectronic devices are another significant area of research strength.

Judging the individual impact of Australian researchers is difficult, and often only revealed by patents that cite Australian papers. The situation is similar in photonics where Australian researchers have taken leadership roles.

New fields of research have emerged in recent years at the intersection of physics and biology. Measuring quantum states in living cells, the brain, neuroscience and photosynthesis is the next big application of quantum mechanics to real systems. Some of this research involves bionic applications, addressing problems in the nanofabrication of hard matter devices which interface with soft (living) matter. In these projects physicists are responsible for identifying how to deconstruct a problem into its component parts, an intrinsic skill needed in both nanoscience and neuroscience.

Energy and power technologies: Materials and systems for solar power are a strong focus of condensed matter physics research in Australia. Researchers are often closely connected to companies which can commercialise their results, but they still address fundamental issues as well as applied problems driven by the industrialisation of PV systems.

At ANU, research activity in PV systems has fed into honours teaching, with the development of a specific program in PV. The University is also developing an “Energy Change” Institute which will house new teaching programs. As expected for a sub-discipline with a strong applied focus, these programs are often conducted outside the traditional departments of physics and located in specialised institutes or engineering faculties.

In addition, there are many research programs around Australia focused on other aspects of energy and power technologies. These endeavours, further from the market, are driven by the quest to develop extreme materials that can withstand hostile, high temperature, high radiation environments with potential applications in thermal power stations including present and future generation nuclear reactors and the International Thermonuclear Experimental Reactor (ITER) project. The potential of the ITER is discussed further in the section below on plasma physics.

Chemical physics: The sub-discipline of chemical physics recently has undergone a substantial change from a focus on molecular spectroscopy and thermodynamics to materials and condensed matter physics. Two distinct strands are evident:

1. *Ab initio* quantum mechanical calculations of materials, mostly liquid, gel and solid/glass phases; and
2. Atomic-, molecular- and macromolecular-scale design and engineering of materials, from host-guest materials (e.g. for gas storage in fuel cells) to biological nano- and meso-scale assemblies (from protein-substrate complexes to cell organelles).

- The advent of large-scale, accessible, supercomputing facilities is driving a better understanding of the structure and performance of materials at even larger scales, above the angstrom-scale, to the 1 to 100 nanometre-scale.

An important driver of innovation in this field is a reappraisal of the role of quantum mechanics. In the past it was thought that it would never be possible to apply basic quantum mechanics to complex chemical systems. But this view has now been overturned. The factors responsible include the rise of supercomputers, the development of new algorithms, advances in many body physics for low energy systems, and the rise since the 1990s of density functional theory for applications to biomolecules of thousands of atoms.

In fact, the crossover of concepts drawn from condensed materials science has also been important. The ready availability of standard computer code has enhanced research and advanced dissemination of these methods into industry. In the near future it is likely there will be a renaissance in the applications of these codes to nanoparticles/surfaces.

Supercomputing: The advent of very powerful computer resources over the past decade has seen the emergence of a third stream of physics research, based on computer simulations, and developing alongside the traditional theoretical and experimental streams. Computer resources can be divided into two categories: high performance (HPC) and peak performance (PPC). HPC facilities include the National Computational Infrastructure Facility (NCI)[77] and also state-based machines for academic research often located within a university, such as ANU's Supercomputer Facility[78]. Most researchers in physics will have access to a local university or department cluster with HPC.

Within Australia, supercomputer facilities are being used in high energy physics, fluid dynamics, materials science/condensed matter physics and electromagnetic physics. Applications include 3D or higher dimensional modelling in fields as diverse as photonic circuit design, analysis of CERN data and lattice quantum chromodynamics (QCD) calculations involving elementary particles such as quarks and gluons. Physics also has a strong influence on supercomputer environmental modelling, structure calculations of large molecules and many other applications requiring numerical models.

Cluster 2: High energy, theory, nuclear and cosmology

Within this cluster lie some of the most fundamental fields of modern physics including particle physics, theoretical and mathematical physics, nuclear physics, astronomical and cosmological physics and plasma physics, and Australia can be proud of the impact that its research community has had on the international stage. As well as contributing to discoveries at the frontiers of modern physics, research in Australia in these fields has already resulted in significant spin-offs, and there is significant potential for contribution to advanced technologies in areas ranging from minerals exploration to medical imaging. The field is supported by major infrastructure within the universities, the CSIRO, and through collaborations with and access to important international laboratories.

There are at present several exciting opportunities for investment that will lead to consolidation and growth of research activities in these sub-disciplines in Australia. These include Associate Membership of CERN, LIGO-Australia, a National Institute to focus theoretical and mathematical physics activities, membership of the ITER, and partnerships with major planned international accelerator laboratories and nuclear facilities.

Bright students are strongly attracted by fields such as theoretical and mathematical physics and particle physics, and Australia must ensure that it has the educational infrastructure to provide them with the courses of study they require to be able participate in research at the forefronts of these fields internationally. As with all students of physics, they represent a resource with the potential for a major return on investment via contribution to a high-tech future for the nation.

Current research focus and global competitiveness

Particle physics: Particle physics research is a major global endeavour, and Australia is playing a growing role in it. The excitement of the quest to identify the Higgs boson or to go beyond the Standard Model of particle physics has attracted enormous public attention and support from funding agencies. The outcomes will have significance for our understanding at the smallest scales we can probe and at the largest scales of the cosmos. Although working at the most extreme end of the innovation continuum, driven by a quest to understand how the Universe works at the most fundamental level, the particle physics community has been responsible for very major spin-offs that have transformed our society. The most visible of these is the World Wide Web. Less

[77] http://nf.nci.org.au/
[78] http://anusf.anu.edu.au/

visible, but also of major importance, are various detector and accelerator technologies with applications to medical diagnostic imaging and therapies.

Theoretical work in QCD involving sub-atomic particles spans a full range from lattice-inspired calculation of equations of state of dense matter to studies of hadron properties and spectroscopy. This is complemented by phenomenology—the application of nuclear and particle theory to experimental work—at leading accelerators around the world, including the Jefferson Lab in Virginia, GSI-FAIR and COSY in Germany, and CERN near Geneva. Substantial activity is emerging around the link between particle physics, astrophysics and cosmology, including application of physics beyond the Standard Model to issues such as dark matter, dark energy and baryogenesis. The long standing problem of reconciling quantum mechanics and general relativity is being pursued with research into super-symmetric quantum field theory and super-gravity theories which have a strong mathematical focus.

Theoretical and mathematical physics: Australia has a long and proud history in theoretical and mathematical physics, with a heritage of strength in statistical mechanics and exactly solvable models. The 2010 Excellence in Research for Australia (ERA) exercise quantified mathematical physics as a discipline of strength within Australia, measured against global metrics, with several universities receiving the maximum possible score of five (well above international standard). Unlike mathematical physics, theoretical physics does not have its own four-digit Field of Research (FoR) code. So, much of the activity in theoretical physics was captured under other the other physics discipline codes.

Research undertaken in Australia encompasses most areas of modern theoretical and mathematical physics, and includes theoretical support for experimental programs in fields including particle and nuclear physics, atomic physics, condensed matter physics, plasma physics and quantum information and computing.

Astronomical and cosmological physics: Much of the activity in this field is captured by the Australian Astronomy Decadal Plan 2006-2015, which has recently undergone a mid-term review. One activity that is seen by the astronomy and astrophysics community to sit within the discipline of physics is the research focused on sources and detection of gravity waves. Several Australian researchers are members of the Laser Interferometer Gravitational-wave Observatory (LIGO) scientific collaboration and participate in the development of interferometer physics and technology and the modelling of potential sources of gravity waves and likely signals that could be detected by LIGO antennas. The successful detection of gravitational waves will enable a new field of gravitational wave astronomy that will open a whole new window on the universe. This window will provide new information on exotic cosmological and astrophysical processes ranging from remnant waves generated by the birth of the universe to the mergers of black holes.

There is also substantial Australian activity at the intersection of particle physics, astrophysics and cosmology. Topics of study include dark matter and energy, neutrino astrophysics, baryogenesis and leptogenesis, astroparticle physics and cosmology, and also physics beyond the Standard Model of particle physics. Theoretical research into the physics of complex quantum systems and nuclear reactions and structure is providing important inputs into astrophysics, including the physics of the early universe. Increases in computing power have provided the capability to describe properties of nuclear matter from fundamental interactions.

Nuclear physics: Australia currently has multi-faceted programs carrying out world-leading research in both fundamental and applied nuclear physics. Major research themes span fundamental research into many-body quantum mechanics, nuclear fusion and interactions, and nuclear astrophysics. Cross-disciplinary research includes materials modification, ion-beam therapy research, radiation damage in materials, and applications in resource exploration, environmental science, nuclear microanalysis and climate science. Australia's ion accelerators play a major role in our international competitiveness. Australia has one of the highest voltage electrostatic accelerators in the world (ANU's 15 Million Volt Heavy Ion Accelerator Facility) which attracts national and international users and collaborations. Australia also has a thriving program in developing new applications of nuclear and X-ray techniques for society and industry, centred on detector technology and applications of radioisotopes in medicine and industry. Theoretical directions include work on nuclear forces using QCD, and applications to astrophysics.

Australia is active in the regional and international arena, being a member of Asian Nuclear Physics Association and chair of the IUPAP Working Group on International Cooperation in Nuclear Physics.

Plasma physics: Research in plasma physics in Australia falls into three broad categories: fusion (ANU), fundamental plasma physics (ANU and Sydney) and plasma applications (Sydney, ANU and CSIRO).

Fusion research includes 3D magnetic plasma confinement, wave physics, and advanced measurement systems. It has recently expanded in directions relevant to the *International Thermonuclear Experimental Reactor* (ITER)—a major international fusion reactor project in France—and other projects with the emergence of burning plasma fusion science. This work embraces challenges of materials, real-time control and suppression of instabilities, plasma diagnostics and plasma theory.

Fundamental plasma research is mainly related to “dusty” (or “complex”) plasmas, and transients in plasmas for materials processing (Sydney). Work on applications, however, is diverse, and includes: thermal plasmas for arc welding and other applications (CSIRO); nanostructure production (CSIRO); plasma surface modification (Sydney); rocket thrusters (ANU, Sydney); fuel cells (ANU); electrostatically confined plasmas as a neutron source (Sydney); polymer synthesis in plasma and micro-plasmas (UniSA); and space plasmas and space weather prediction (Sydney). Work on atmospheric-pressure plasmas is recovering after CSIRO reduced activity in this field. There is now a small but expanding group in CSIRO Materials Science and Engineering, work at ANU on non-equilibrium discharges and a new group at Swinburne University focusing on plasma spraying and other thermal plasma applications.

Cluster 3: Photonics, quantum information, atom optics

This cluster includes the fields of optics and photonics, quantum information and computing and atom optics.

Optical physics extends well beyond the widespread applications of imaging, cameras, telescopes and microscopes. Optics plays a fundamental role in many sensing applications, including medical diagnosis, industrial processing and environmental and climate research. Via optical fibre, photonics is the backbone of all long distance communication, and will provide the high communication bandwidth we want for all activities. Lasers are now a preferred tool in manufacturing, from heavy duty welding for cars and ships to micrometer precise printing and cutting.

Precision measurements and metrology have been one of the core drivers of contemporary industrial design and manufacturing, allowing the mass production of highly reliable products. Recently, technology has advanced to a stage where the effects of optics can also be reproduced and enhanced in atoms, which act as matter waves. Atom optics spans the world of light, as in photons, and heavy particles, as in atoms. Based on the technology of laser cooling, ultra-cold atoms and Bose Einstein Condensates we can now build atom lasers, coherent matter wave interferometers and new optical clocks that will extend the sensitivity of sensors, in space and on earth.

At the same time we are investigating how to use the quantum property of entanglement for entirely new applications. This second quantum revolution is concerned with our ability to create, transmit and process information—to generate amazing increases in processing speed, but also potentially to develop new devices that can emulate physical systems and materials that have been too complex to understand until now. Some of these are biological systems—which are not at all well understood.

While quantum information might be one tool for doing this, there are many other areas where classical physics, new optical and electronic instrumentation, and new ideas for imaging will allow us to understand the operation of biological samples, providing new medical diagnostic and treatment techniques, or enhancing our human capabilities.

In all these areas Australia continues to make contributions, through university research teams, ARC Centres of Excellence, and groups at CSIRO and the National Measurement Institute (NMI) that are internationally admired and an integral part of global research networks. Australian-trained scientists are playing a major role in many international research laboratories, and Australian ideas are implemented by scientists and engineers across the world.

Optical interferometers with sensitivities sufficient to detect gravitational waves will come online around 2014. Observing the gravitational signatures of violent cosmological events will open a completely new window on the universe. Research teams in Australia—at ANU, UWA and Adelaide University and CSIRO—have been important contributors for many years to the development of technology for this global observatory. They have created technologies and systems for controlling kilometre-scale interferometers which are now being installed in detectors in the US, and have demonstrated techniques, such as squeezed light, to improve sensitivity even more. The proposed LIGO-Australia project would provide an opportunity to establish the vital southern hemisphere node of the global observatory, and would result in a significant research facility located in Australia, using Australian and international know-how and providing access to a new type of astronomy.

Current research focus and global competitiveness

Optics and photonics: The strength of optical physics in Australia is recognised by the scale and depth of research programs. They range from theoretically focused research, through optical materials research, to micro- and nano-fabrication and device development. One characteristic that marks this sub-discipline within Australia is the degree to which these elements work together effectively. Some notable examples include glass chemistry, atmospheric science and astrophysics.

Australia has substantial investment and accomplishment in the field of optics and photonics, and is also well integrated into global activities. Significant research programs exist in several institutions. There is a critical mass in metamaterials supported by excellent nanofabrication infrastructure, in large-scale photonics, in materials science studies including new glasses, and in photonic integrated circuits. A large program in quantum photonics with links to photonic integration and quantum information also exists.

Some of the most important areas of recent growth within optics are nano-optics, plasmonics and communications. In communications, the development of nano-antennas and single photon sources has been very promising. Use of the Australian Synchrotron is ramping up rapidly. Substantially more work is needed in the areas of imaging, quantum imaging, spectroscopy and sensors. And an increasing demand for environmental remote sensing, driven by a need for tools to monitor climate change and to support the development and deployment of renewable energy technologies, is also evident.

Quantum information and computation: Quantum physics is one of the most successful models ever formulated for describing the physical world around us. In the past century, it has been responsible for the invention of the transistor, the television, nuclear energy, and other life changing technologies. Quantum information science is an emerging field of research that amalgamates quantum physics and information theory. It is anticipated that the 21st century will deliver a second wave of the quantum technological revolution where deep concepts of the microscopic world will again provide unprecedented benefits to the society. Two promising outcomes of this revolution are the quantum computer—a device that can provide an exponential scale-up of computing power—and quantum cryptography—a method of communication that guarantees absolute security.

The development of a quantum computer is widely recognised as one of the 10 major challenges confronting science and engineering in the 21st century, and the international race to construct such a computer is of the highest technological calibre. Quantum cryptography, or more precisely quantum key distribution, is a new paradigm in data encryption. While most modern advanced encryption protocols use mathematical complexity for ensuring information security, the advent of a quantum computer, or the invention of a more efficient mathematical algorithm, may render such encryption protocols insecure. In contrast, quantum cryptography relies on the laws of physics for its information security. As such, an ideal quantum cryptographic system is unbreakable, leading to absolute information security.

Most of the revolutionary new technologies introduced in the second half of the last century were based on the quantum revolution which opened the way to the development of semiconductor transistors, lasers, giant magnetic resonance etc. Significant research effort is now being applied to initiate a second revolution of quantum technology related to the exploitation of the full spectrum of quantum behaviour in systems both for fundamental science and emergent technologies. Fragile quantum phenomena such as entanglement and coherence have significant potential for new information technology applications.

One of the breakthroughs has been the development of scalable quantum computing technologies. Substantial effort has been applied over the past decade in optical and solid state quantum computing both in theory and experiment. The motivation for this type of research is to solve problems that cannot be solved using a classical computer, and to develop entirely secure communications systems. Yet there are many other ramifications.

This work is also driven by a quest to understand quantum mechanics itself better, and to develop new experimental systems capable of exploring quantum phenomena in the laboratory. Australian quantum science engages in research into semiconductors, neutral atoms, ion traps, superconducting circuits, opto-mechanics, photons and quantum dots. This amounts to great breadth for a country the size of Australia while maintaining the necessary depth. So strong engagement with international endeavours through the exchange of staff and collaborative cross-border research projects are needed to address this issue.

Atom optics: The ability to cool and trap atoms with laser beams has inspired a revolution in atomic physics. It has allowed the generation of Bose-Einstein condensates (BEC), where atoms and molecules are all at the same energy level, and, more recently, the development of degenerate Fermi gases. Not only has this involved record cold temperatures of the samples, now in the range of nano-Kelvins, but is has also created the opportunity to observe directly the properties of a macroscopic quantum system.

In the past 10 years this has been one of the most rapidly growing fields in atomic physics—and Australia is regarded as one of the strongest players in this field, comparable to one of the leading countries in Europe and with more activity than any Asian country, including China. The key global conferences which have been held in Australia are evidence for this. This pre-eminence has been achieved through a strong collaborative approach across Australia and New Zealand, linking all groups active in experiments and theory in this field.

The research focus is on understanding the properties of a macroscopic quantum system, which includes all the consequences of many particle entanglement, effects such as super fluidity, as well as spatial correlations. In a pure BEC all the atoms are in one quantum state. This can be exploited in several ways. For instance, it can be used to create a coherent matter wave in the form of an atom laser. And Australian teams have developed the most advanced of these instruments.

The understanding of the complete details of the structure of atoms and their interactions in collisions is the focus of several highly successful research teams in Australia. Groups from several universities studying the theory of this have made seminal contributions—in the development in particular of the very specialised numerical models required to describe complex atoms, including antimatter. Experimental facilities exist at several laboratories to test these predictions. By exploring the interaction between electrons and positrons we not only expand our fundamental understanding of matter, but also can develop applications in biology, materials research and medicine. The recently installed PET scanners in our hospitals are one of the most prominent of these.

Cluster 4: Applied physics

This cluster includes the following fields:

- Medical physics & biological physics
- Industrial physics
- Climate and atmospheric physics
- Hypersonics and fluid mechanics
- Geophysics
- Acoustic physics
- Space physics

This is a diverse group of disciplines with a broad range of levels of achievement and issues. Many of the areas are producing world-class research outcomes, though some involve a subcritical mass of researchers and achieve through active, high-level, international collaborations. Even for the smallest of sub-disciplines there is clear evidence of valuable future research directions to address critical community-based problems. This can only be achieved, however, with investment in staff and international support.

Evidence of the depth and breadth of work can be obtained from the report *An Australian Strategic Plan for Earth Observations from Space* (ATSE July 2009). In many areas the success of today can be traced to "investments" made 10-20 years ago, and with a continuity of support. Other research areas are equally successful but "invisible" in the current classification for ERA which has no categories for medical physics, acoustics or industrial physics.

As much of the research in this collection of disciplines involves interdisciplinary fields, it is of significant concern that funding for interdisciplinary science is not adequately supported under current schemes. We need a better mechanism for capturing and promoting the true value of interdisciplinary projects and for taking advantage of their high potential to add value.

Current research focus and global competitiveness

Hypersonics and fluid mechanics: space physics: The Australian Federation Satellite (FedSat) program led to significant achievements and highly visible success in space physics. In fact, the field of astronomy and space science is one of Australia's great strengths. It scored a national ERA rating of 4.2. Some of these areas overlap strongly with earth sciences which also achieved one of the highest two-digit overall rating (3.8) in the ERA process.

Climate and atmospheric physics: Climate and atmospheric physics is not strongly represented at the universities. Much of the research is based in the Bureau of Meteorology and CSIRO. Focus in the recent past has shifted from remote sensing using field stations to computation. This has resulted in an increase of climate modellers, who study the fundamental driving processes, at the expense of climate physicists.

Acoustics: There are solid achievements and ongoing research into cochlear implants. Cochlear Ltd, based in Sydney, makes two-thirds of all such implants in the world.

Medical physics and biological physics: The medical physics community in Australia has made relatively substantial contributions both at national and international levels to radiation therapy and oncology, medical imaging, nuclear medicine, nano-dosimetry and radiobiology, as well as to the development of medical devices such as the internationally renowned cochlear implant. Radiation therapy has been a major research focus and this can be attributed largely to ongoing federal and state government support of professional training programs in that sub-discipline.

The current research focus of biological physics in Australia is difficult to identify owing to the scattered distribution of disparate multidisciplinary research activities, although a significant area is modelling the biological activity of the brain, widely known as computational neuroscience. Globally, biological physics is recognised as an active cross-disciplinary research area, encompassing themes such as mechanosensing, microrheology, biophotonics, microfluidics, soft matter physics and self-assembly. The dynamic scale is vast, ranging from single-molecules to macro-molecules, cells, tissues and organs. A current focus in Australia is in the areas of ion channels and the electrophysiology of membranes. This largely involves computational modelling with simulations of molecular dynamics.

INTERNATIONALISATION OF PHYSICS RESEARCH

Key points

- There has been a considerable increase in the number of research publications globally. Australia is one of the leading nations in terms of increase in Annual publication rate, however, the emerging nations such as China have made a significant impact in terms of research publication outputs.
- The USA's dominance in terms of publication rate has been overtaken by nations of the European Union.
- The emerging nations such as China, India and Brazil are challenging both the USA and the EU in terms of research outputs.
- The USA remains dominant in terms of citation impact factor.
- There has been a gradual increase in percentage of publications that are a result of international collaboration.
- The USA is the major destination for collaboration both for Australia and for emerging nations.
- Opportunities for international collaboration with India and China exist for Australia.
- Australian government initiatives are helping to facilitate international collaboration but some limitations to collaboration exist such as a lack of clear strategies for international collaboration as well as a lack of bilateral schemes and formal international agreements.

The international status of research publication

Over the last three years Thompson Reuters have analysed the *general* global research landscape across a number of science disciplines and research fields and have released a number of regional research reports. Amongst them are reports on the research publication performance of the USA, Brazil, Russia, and the Asia Pacific region, including Australia[79,80,81].

Historically, the USA has been the world leader in scientific research publications and outputs, a trend that continues today. However, whilst three decades ago scientists from the USA produced almost 40% of the publications in journals indexed by Thomson Reuters in the Web of Science, in 2010 the share of publications has become more evenly spread globally with only 29% of papers having US co-authors. Nations from the European Union increased their share of research papers to 36% of global publications, surpassing the USA in the mid 1990s. The Australian share of global publications has been growing steadily from 2.85% in 1999 to reach 3.18% in 2008 with the volume of Australian publications rising annually by an average of nearly 5%, and reaching over 36,000 publications in 2008. This growth is higher than that of other selected OECD countries and of world, OECD and EU-27 publication averages. China has also shown a substantial increase in research publication rate. For example, in the area of materials science, which is strongly interdisciplinary and requires scientific collaboration and for which physics is a major contributor, China has grown from a barely detectable presence with fewer than 50 papers in the field in 1981, to become the largest producer of publications and has overtaken Japan, the USA and is challenging the combined output of well-established European research economies; in comparison, Australia ranks 14th of 35 countries identified by Thompson Reuters in this field[82].

[79] Thompson Reuters: Global Research Report USA November 2010
[80] Thompson Reuters: Global Research Report Brazil June 2009
[81] Thompson Reuters: Global Research Report Australia and New Zealand March 2010
[82] Thompson Reuters: Global Research Report Materials Science and Technology June 2011

The change in international publication rates, such that the USA is no longer the major producer of publications, may in part be explained by the marked increase in publication rates of emerging nations and also by an increase in the percentage of publications that are the result of international collaboration. Today over 35% of science articles published in international journals are internationally collaborative, which is an increase of 10% over the last 15 years[83].

Despite the decrease in the percentage of publications with co-authors from the USA, in terms of citation impact, the USA remains dominant, followed by the European Union. For example, US papers in materials science earn an average of 73% more citations per paper than the world average and the USA achieves the highest relative citation impact scores in this field compared to all other fields. Western Europe, well represented through the Max Planck Institutes, CNRS and CSIC, also retains a high average impact. However, the gap in citation impact between Asia, and Europe and North America, is starting to close.

Whilst the US research sector is going from strength to strength and the leading institutions continue to assert an exceptional dominance when compared to leading research institutions in Europe and Asia, the USA's relative international research competitiveness is increasingly being challenged by the emerging nations such as China, India, and Brazil who are expected to increase their investments in research as a percentage of GDP over the coming decades in order to build a research foundation for the future.

Thompson Reuters expect collaboration within the Asia Pacific region to become an increasingly important policy issue for Australia. Collaboration with China and India is particularly important, as the Australian research competencies complement the technological strength and capacity of these nations. Strengthening of collaboration with these new partners is expected to add to the diversity of both disciplinary and cultural approaches in the Asia-Pacific region and could lead to increased challenges to traditional research relationships. Although research collaborations with Australia's traditional Anglophone research partners still produce 80% of the publications evaluated by Thompson Reuters, close to 9% of collaborative publications were co-authored by scientists of the Chinese Academy of Science and the remaining 11% with scientists in five other Asian countries[84]. Collaboration with other nations such as Brazil, also remains an opportunity for Australia.

At this point in time publications from emerging countries such as China are not highly ranked in terms of citation impact. In the Australian Innovation System Review 2010, the impact of Australian physics in terms of the relative citation index (RCI) is the highest for all science disciplines[85] (Figure 17), and is just ahead of geociences. The RCI takes into account the variation in discipline citation rates as it divides the Australian citation rate by that for the rest of the world, and hence is a good measure of relative discipline performance. Once again, the RCI reveals Physics to be a national research strength.

[83] Knowledge, Networks and Nations – Global scientific collaboration in the 21st Century, Royal Society Report 2011
http://royalsociety.org/uploadedFiles/Royal_Society_Content/policy/publications/2011/4294976134.pdf

[84] Thompson Reuters: Global Research Report Australia and New Zealand March 2010

[85] Australian Innovation System Report 2010

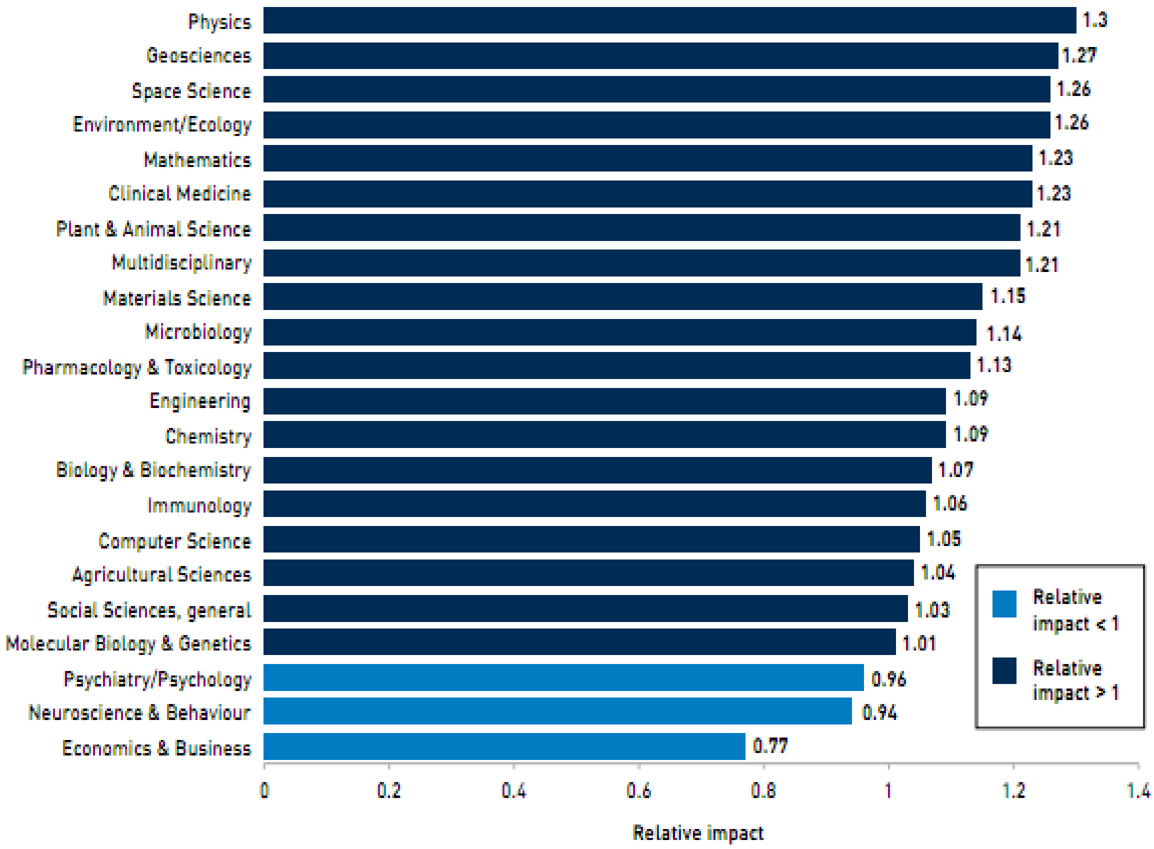

Figure 17 Relative impact of Australian scientific publications by field (2004 to 2008) Source: Australian Innovation System Report 2010

Tracking of the Australian publications record in three of the most important global scientific physics journals in comparison with countries of similar size, shows that Australian physics has increasing impact (Figures 18-20) and that there is also a slowly increasing trend towards collaborative publications with researchers in the USA and England.

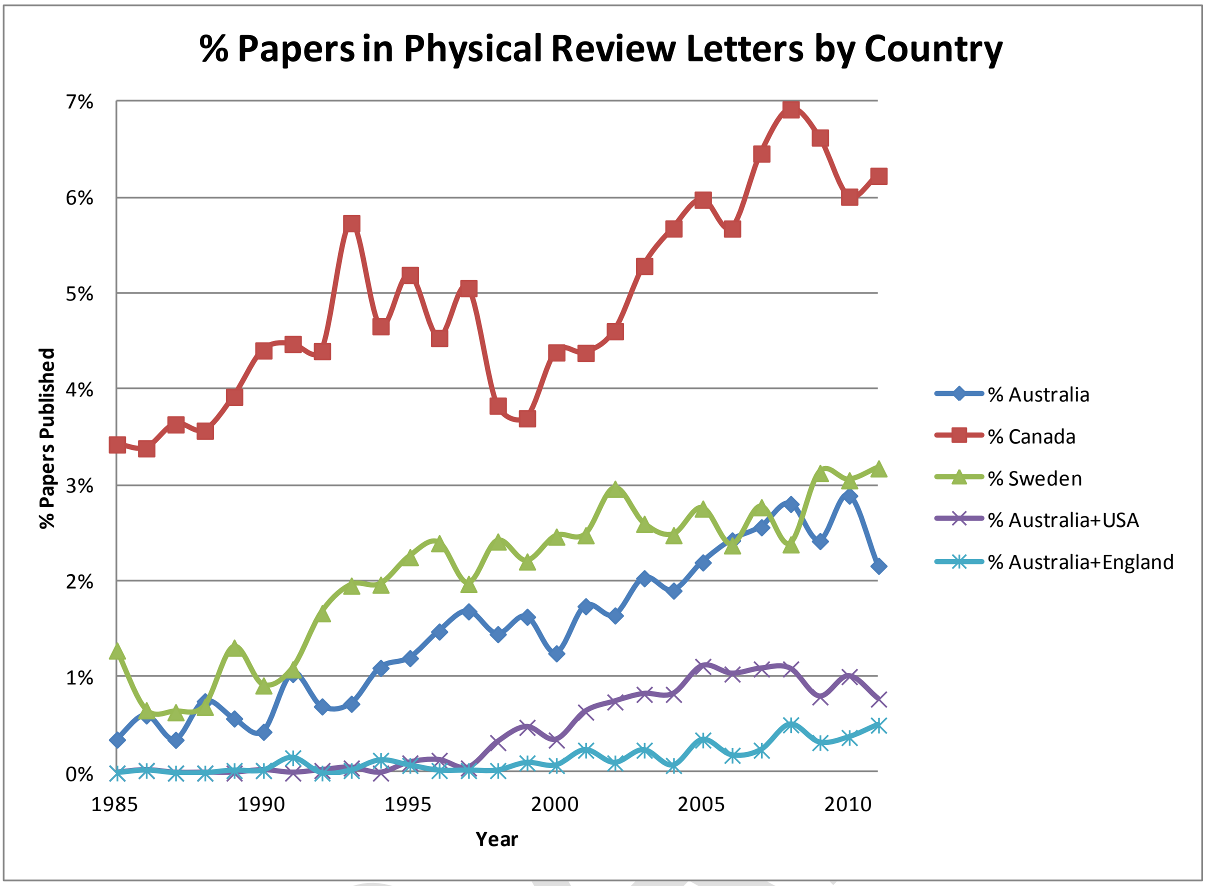

Figure 18 Proportion of Australian physics publications in Physical Review Letters by country

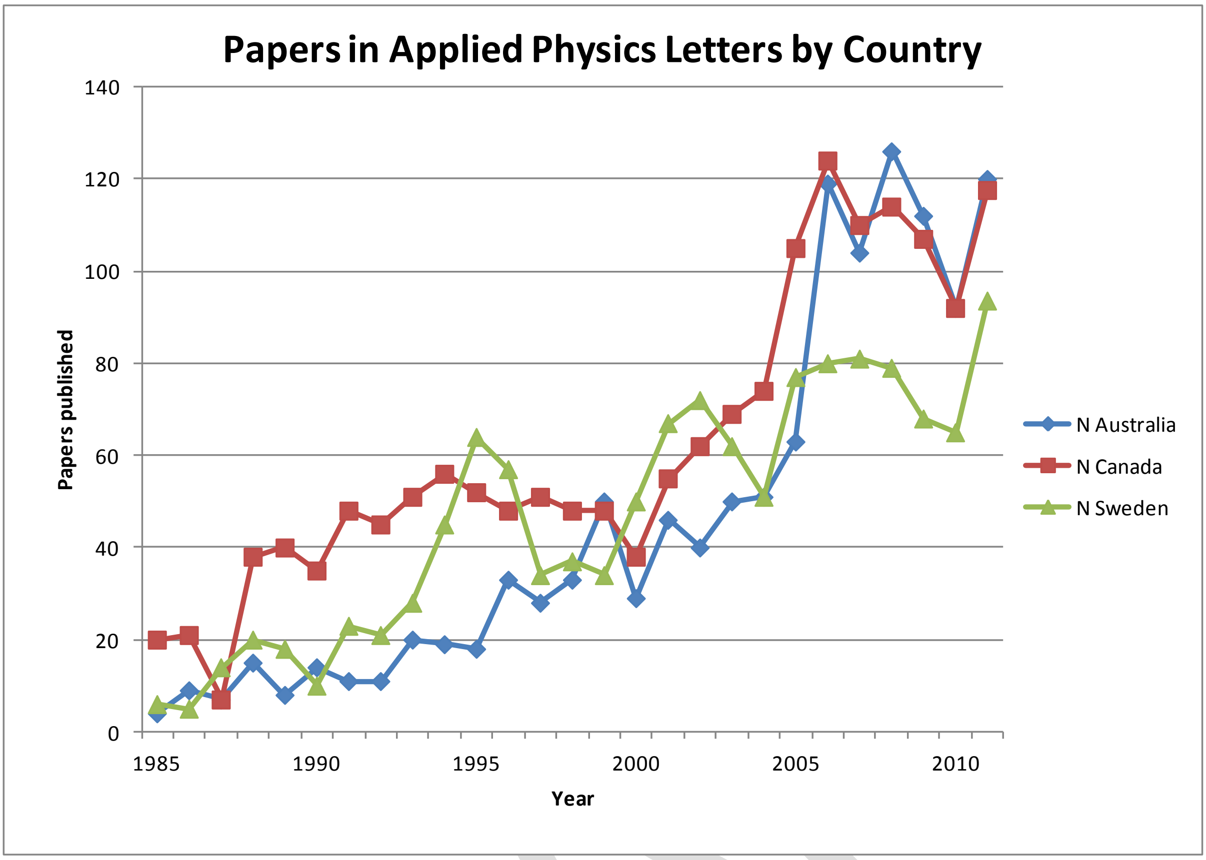

Figure 19 Number of publications by country in Applied Physics Letters

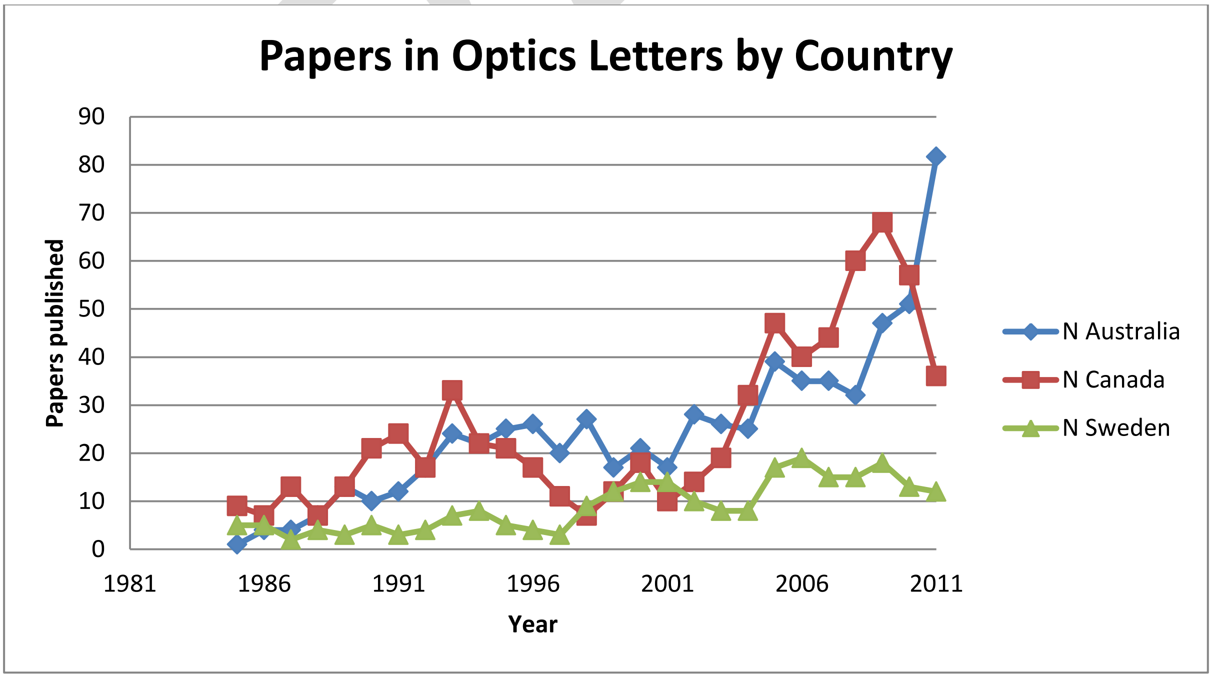

Figure 20 Number of publications by country in Optics Letters

Australia as an international collaborator in physics

Australia is a well integrated player in the international physics community, with Australian physicists collaborating with many international teams, addressing the big research questions in physics. The Academy of Science is a strong promoter of the internationalisation of Australian science and research[86]. The Royal Society also recognises that the fostering, maintenance and strengthening of international scientific collaboration is a necessary strategic imperative for addressing major global challenges[87]. International capacity building is seen as crucial to ensure that the impacts of scientific research are shared globally.

Despite these global collaborative sentiments, Australia's collaboration is predominantly with North America, Europe and the UK. Although collaboration with the Chinese Academy of Science is increasing, research collaborations with other emerging nations are currently not as well established. The globalisation and internationalisation of research leads to fierce competition for attracting international talent in all physics sub-disciplines worldwide. The USA benefits most from globalization due to its ability to attract world-class scientists from most countries. It is the predominant research destination for researchers from all global regions. For example, the USA is the most important research collaborator for India, whose research productivity is expected to overtake most G8 nations between 2015-2020[88]. In comparison, Australia is only India's 9th most important research partner based on research publication output, despite the fact that our research capabilities complement India's technological capacity.

Also surprising is Australia's lack of collaboration with Russia. Currently, the areas of strength in Russia's research are in the basic sciences, especially physics, with 7.39% of global research outputs between 2004 and 2008 and although Russian and Ukrainian physicists and mathematicians are highly qualified and sought-after in both the Australian research sector and in many technology and resource based industries, Russia's most important collaborator is the USA; it closely collaborates with nine other European nations, and in Asia with Japan, China and South Korea. However, Australia does not feature as a collaborator on the list of Russia's top 14 collaborator nations. Similarly, although Brazil produced 2.8% of the world's publications in Physics in 2007-2008, it does not attract many collaborators from Australia.

According to Thompson Reuters, three important and internationally active research areas to which physics is a contributor include graphene; metal-organic frameworks; and electrospun nanofibrous scaffolds for tissue engineering applications. The standard of US research in these fields remains at the leading edge. Other research areas in which significant opportunity for international collaboration exist include new research fronts in nanotechnology which are closely linked to research fronts in quantum physics, superconductivity, astrophysics, solar cell and fuel cell research fields. The youngest core literature is associated with molecular logic circuits, upconversion fluorescent rare-earth nanocrystals, and selfassembling supramolecular nanostructed gel-phase materials.

In many cases Australians are given access to international physics research groups and laboratories in these and other research fields and this allows Australian physicists to capitalise on international investments made in existing research infrastructure, including research infrastructure that is beyond the means of any single nation to build and maintain. For example, Australian partners in major EU FP7 consortia leverage facilities and expertise not currently available in Australia, with the clear benefits of technology transfer.

Within physics there are some impediments to internationalisation of research including a lack of evidence of clear international collaboration strategies and roadmaps. There is also a lack of bilateral schemes and formal

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[86] Internationalisation of Australian Science, The Australian Academy of Science 2010. http://www.science.org.au/publications/documents/Internationalisation-of-Australian-Science.pdf

[87] Knowledge, Networks and Nations – Global scientific collaboration in the 21st Century, Royal Society Report 2011. http://royalsociety.org/uploadedFiles/Royal_Society_Content/policy/publications/2011/4294976134.pdf

[88] Thompson Reuters: Global Research Report India October 2009

agreements with other countries, including with Asian research agencies and countries. Existing constraints related to achieving critical mass in student numbers in individual institutions in teaching advanced programs, for example in theoretical physics, at a norm that is comparable with international standards, makes it difficult to achieve international impact across some of the physics sub-disciplines.

In recognising its importance, the current Australian Government has made some effort to facilitate Australia's international scientific collaboration. As well as opening up the ARC grants programs to international competition, changes to the eligibility of foreign owned companies conducting research in Australia for the R&D tax concession were introduced under the Powering Ideas agenda. In addition, funding has been committed to international astronomy projects such as the Giant Magellan Telescope and the Square Kilometre Array under the Super Science initiative. The ARC Centres of Excellence have also provided a tremendous vehicle for Australian physics research to prosper in the Australian research landscape, and there is great potential for these centres to propel Australian physics research further forward in the global physics research community and foster and drive international collaboration. It is imperative that this opportunity be realised.

INDUSTRY AND BUSINESS

Key points

- Although Australian business expenditure on research and development is climbing steadily, the percentage funded by government is very small.
- Australia ranks poorly in terms of new products introduced to market.
- Research organisations are the creators of new knowledge that seeds the innovation pipeline. However, industry does not see universities as a valuable collaborator. The propensity for universities to publish rather that protect valuable intellectual property may contribute to this seeming lack of willingness to collaborate.
- A number of successful models of industry collaboration with universities exist, for example in the mining, ICT and biomedical industries.
- Commercialisation income can provide a useful indicator of the depth and productivity of research organisation/industry interaction. Historically, universities have received little commercial income.
- Industry is a major employer of physicists, but it is difficult to accurately establish the number of physicists employed across the different industry sectors.

The industry and business segment in Australia is very active in research and development and contributed (by funding) 68% of the increase in total gross expenditure on research and development (GERD) from 1984-85 to 2006-2007. This compares to 24% of GERD increase by the Australian government and 25% by the higher education sector.

Australia's business expenditure on research and development (BERD) has been climbing steadily over the last decade (Figure 21). However, in 2007, only 3% of it was financed by government. This figure is comparatively low compared to other OECD countries, ranking Australia 25th on this innovation indicator. The number of businesses that introduced new products, i.e. technological innovations that were new to the world was 12% of large firms and 7% of small to medium enterprises. This placed Australia at the bottom of the OECD table on this indicator, ranked 26th and 24th respectively. Australia ranked 15th out of 19 OECD countries for the manufacturing sector and 17th out of 18 countries for the service sector in terms of non-technical innovations.

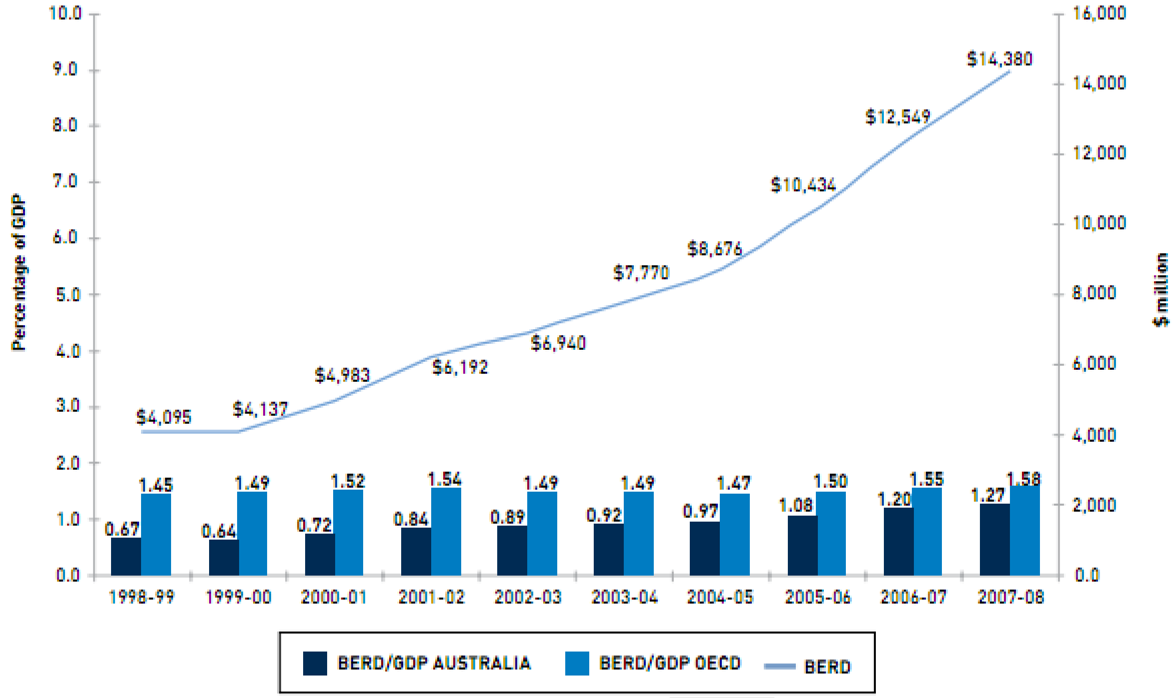

Figure 21 Business expenditure on R&D, 1988-89 to 2007-08 [89]

In 2008-09 the top three innovating sectors were wholesale trade, manufacturing and retail trade with the number of innovating firms in those sectors being 46.3%, 42.2% and 39.6 of businesses (Figure22).

Percentage of innovating businesses by industry sector and the corresponding gross value added (GVA), 2008-09[6,8]

Industry Sector*	Innovating businesses (%)	GVA ($million)	Industry share of GVA (%)
Wholesale Trade	43.6	61,403	4.9
Manufacturing	42.2	117,793	9.4
Retail Trade	39.6	58,897	4.7
Information Media and Telecommunications	39.2	42,606	3.4
Arts and Recreation Services	39.1	10,025	0.8
Financial and Insurance Services	38.6	135,337	10.8
Professional, Scientific and Technical Services	37.8	76,440	6.1
Rental, Hiring and Real Estate Services	37.2	37,594	3.0
Accommodation and Food Services	36.0	31,328	2.5
Other Services	34.0	25,062	2.0
Administrative and Support Services	32.9	33,834	2.7
Health Care and Social Assistance	32.0	76,440	6.1
Electricity, Gas, Water and Waste Services	31.4	31,328	2.5
Mining	31.3	96,490	7.7
Transport, Postal and Warehousing	29.3	72,681	5.8
Construction	26.2	92,731	7.4
Total	**35.0**	**999,991**	**79.8**

* Innovation data is not available for the sectors *Agriculture, forestry and fishing; Public administration and safety; and Education and training.*

Figure 22 Percentage of innovating businesses in 2008/09 [90]

[89] Australian Innovation System Report 2010, Commonwealth of Australia 2010
[90] Australian key innovation indicators, updated 2011 http://www.innovation.gov.au/Innovation/ReportsandStudies/Documents/InnovationIndicatorsdatacardFeb2011.pdf

Much of this innovation, however, is process innovation and not technology innovation. Australia's distance from the top OECD countries in innovative activities ranges between 47% and 77%.

"Mostly in Australia, there's a technology push by academics and not from industry need. Australian research facilities that look at our problems build a program to supply the solutions. The academic cycle of learning what the problem is and devising a solution is way too long, in the Australian region, mostly."
Industry representative

Australia's research organisations could, in theory, be seen as creators of new knowledge that can form the seed for technology innovations. However, business and industry do not see universities as a valuable source for collaborative research or a source of innovative ideas or usable research outputs (Figure 23). The causes of this have not been explored in detail but one cause might be the preference of new knowledge creating organisations such as universities, to publish rather than to identify intellectual property (IP) that might be of value and therefore protect it via the patenting process. Another cause might be unawareness of the creators of research results and of the applicability of these results in terms of practical application and value to business and potential end users. A third reason identified by industry is the inaccessibility of information relating to what IP and research results exist within the research sector that might be of value to industry. Finally the difficult and tedious process of commercialising IP from physics research may influence scientists and research teams in their preference to publish instead of commercialise. The perception held by many researchers in the academic sector that industry-based research is purely mission-focused or directed contract research and therefore would result in a loss of freedom to pursue fundamental research goals may be a fourth reason for the limited research collaboration of the research sector, and especially universities, with industry and business.

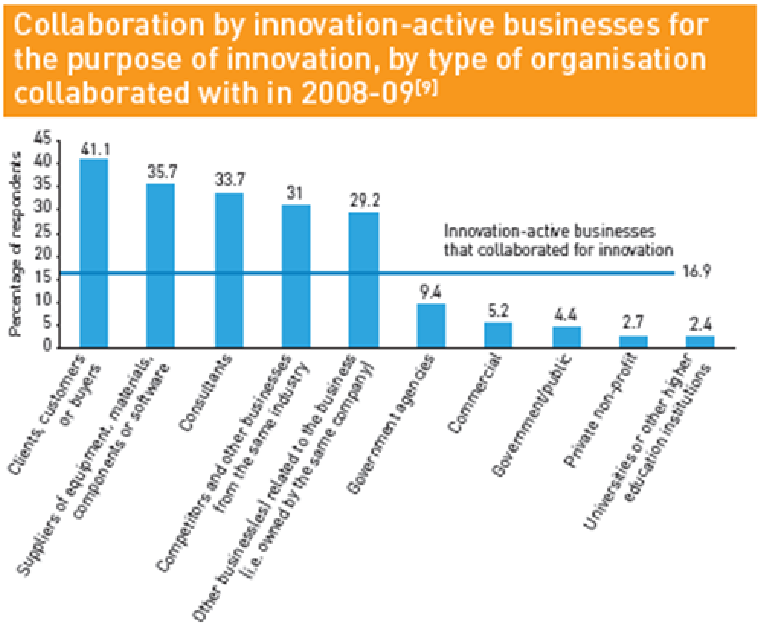

Figure 23 Collaboration by industry with potential sources of innovation[91]

[91] Australian key innovation indicators, updated 2011 http://www.innovation.gov.au/Innovation/ReportsandStudies/Documents/InnovationIndicatorsdatacardFeb2011.pdf

Industry and business segments that conduct R&D with the input and skills of physicists

The perception held by many researchers in the academic sector that industry-based research is purely mission-focused or directed contract research and therefore would result in a loss of freedom to pursue fundamental research goals has led to limited research collaboration of universities, with industry and business. Industry and business do engage with the research sector but Australian research providers are only one of a multitude available to industry globally.

Any business or company can engage any research organisation globally for R&D services. There are many different models that companies use for sourcing new ideas, new IP, new skills and new employees. As the risk of failure of R&D projects is high, business tries to reduce the risk of financial loss by focusing on the track record of the research provider in terms of research excellence. They rarely commit all research funds to one research provider, but if no other equally excellent providers exist, they use other risk management strategies such as their own project management expertise within the research organisation to reduce the size of risk of project failures. Examples of industry and business segments that conduct R&D with the input of physicists in Australia include:

- Mining and resource companies – R&D for exploration, extraction, processing, mine remediation etc (employs geophysicists but also physicists that are given geology training),
- ICT industry – product, process and service related R&D
- Biomedical industry – design of equipment and diagnostic processes
- Scientific instrument manufacturers – R&D, instrument service and sales
- Aeronautical and Space agencies – R&D
- Automotive - R&D
- Financial services – financial and risk modelling
- Law firms, patent attorneys, patent examiners, IP Australia
- Scientific publishers employing physicists
- Science communicators and writers
- Consultants and experts (such as forensic physicists).

Examples of different models of industry collaboration with universities and other research providers are listed in Table 49.

Model	Advantage for company	Disadvantage for company	Comments
Short-term contract research at full cost	All IP owned by company. Mostly used For smaller projects at the applied end of the research scale. Tendency to contract to close-by research providers.	Project management skills of research providers low. Time lags to project start often exceed company expectations.	Manufacturing companies may seek support in solving specific Applied problems which might be of low to moderate interest to the research provider. Initiatives such as the opportunity provided by government to place a scientist in an industry company for a few months is not aligned with current research career metrics.
CRC model	Access to a number of research providers.	IP policies of CRCs only conducive to research on industry problems that do not directly affect the competitiveness of individual companies. Lag time to application of research long.	Advanced manufacturing CRC
Medium term research project at shared costs (e.g. three years) with research department and individual research leaders.	Access to specific research providers in the field of expertise required without having to invest in long-term employment and infrastructure, use of research provider skills and infrastructure.	Poor project management skills of research providers, IP policies of research providers may be too disadvantageous to deal with.	Management of expectations of both parties is often an issue. Model often used by companies who want to have exclusive rights to the beneficial use of the created IP. Increasingly companies take on the role of project management to reduce the risk of delays and cost overruns.
Long-term collaborative programs with research providers in their country of operation.	Long term partnership at department and/or organisational level, usually for a number of years. Access to research infrastructure and skills. Can pick and choose research providers globally .	Management of expectations and management of projects and long-term programs. The best research groups might not be in countries where the company has their headquarters or their R&D department. Taxation regulations may not make setting up of long-term relationships easy or profitable.	Several different models such as contracts amounting to several millions to multimillions, setting up of industry research centres on campuses with related infrastructure, or co-location of separately funded and operating industry and research provider research groups. Tendency to establish long term relationships where the end markets for products are and where there is already an established R&D footprint of the company in the country.
Open innovation	Create and exploit new sources of ideas and IP.	Often ill-defined goals and expectation and resulting confusion.	Difficult to manage and track and capture mutual benefits. IP issues need to be dealt with up front.

Table 49 Different models of industry collaboration with research providers

Australian physics departments are most often involved in the top three models of industry interaction. Long term collaborative programs require that substantial trust has been developed and continues to exist between the research provider organisation and the industry company. In general, dedicated research centres are only set up by large companies. Two examples are Rio Tinto which has a number of collaborative research centres in Australia and overseas, IBM which has a number of relationships and R&D investments in Australia, and Siemens which has a sophisticated multi-tiered approach to university based R&D in which the top tier consists of a small number of research organisations with long term strategic importance to Siemens. These top tier research organisations are located in countries in which Siemens has its own established research facilities and a substantial commercial presence. A good example of an established long-term research relationship with a physics research team in Australia is provided in Box 1.

Box 1: RIO TINTO Collaboration with the University of Western Australia

Rio Tinto is funding a major research program in the School of Physics at the University of Western Australia (UWA) for the development of a cryogenic airborne gravity gradiometer for minerals exploration. The key IP was a spin-off from work on a resonant bar gravity wave detector at UWA. The project has a number of features that provide an interesting model for industry-university partnership on research that has outcomes directly relevant to industry. Whilst most of the research and technical staff on the project are employed through UWA, project management and oversight is provided via Rio Tinto staff, a number of whom are located at UWA. Whilst making use of infrastructure at UWA (for which there is an infrastructure charge), particularly the workshop, there has been significant co-investment by the School and Rio Tinto in new infrastructure necessary to progress the project in a timely manner. This infrastructure is available to other researchers in the School, but with priority for the industry partner. The project has also led to the implementation of an industry standard health and safety culture in a university research environment.

An indicator of the depth and productivity of research organisation/industry interaction can be estimated from the amount of commercialisation income research providers receive annually. However, this is to a very large degree influenced by the IP and commercialisation strategies of the individual research provider organisations. The university sector in general receives very little commercialisation income from IP licenses or the sale of start-up companies in which they own equity. It has not been common for Australian research provider organisations to keep equity in spin-out companies with the aim of reaping benefits later from added value to the company value over time as technologies are developed into prototypes and eventually marketable products.

According to the ERA Report 2010, the commercialisation income for all of the physical sciences (Code 02) was $7.24 million over the three year reporting period. Adding the commercialisation income from both mathematical physics (0104) and geophysics (0404) adds an extra $51,150 to the total.

Industry as a major employer of physicists

Industry is a major employer of physicists because of their high mathematical and problem solving competencies. Approximately one third of job advertisements in Seek, both in April and May 2011 stating physics qualifications as a job requirement, were placed by the private sector (Table 6)[92]. Interestingly, many of these job advertisements were looking for employees with a science background, such as physics, mathematics or engineering, and many jobs stated that a background in physics was required.

[92] Prescott, J.R: Jobs in Physics in 2003: An unusual year. http://www.physics.adelaide.edu.au/jobs/AIP_JobsReview03.html

At this point in time there is no information available on the number of physicists working in large business or industry companies or in small and medium enterprises, and therefore their contribution to the success of Australian business and industry innovation cannot be substantiated or quantified.

The resources industry tries to overcome shortages in physics and mathematics skills by sourcing physicists, engineers and mathematicians from overseas and often from former Eastern-Bloc countries such as Russia and Ukraine.

CAPTURING THE FULL HUMAN POTENTIAL

Key points

- The process of women choosing against a physics career begins at an early age, often before finishing school.
- There is a gender imbalance across all sectors of the physics community.
- The university sector may have become a less attractive career option for women, which is evidenced by an imbalance in the number of women who enter the university sector and those who leave it.
- There is a marked difference in the career paths of men and women due to differences in family care taker responsibilities and in needing to adapt to the career needs of a partner.
- Despite there not being a coordinated approach to assisting women into the physics workplace, there is general goodwill across the physics community and there are a number of eminent female physicists who have been appointed to major government and public roles.
- There is limited visibility of the career options available in physics and of the opportunities for career progression.
- Research productivity is mostly measured in terms of research publication outputs and impact.
- The funding application process and the high level of competition for available funding result in productivity losses of approximately 20% for each researcher in the university sector.
- Most of the research metrics used to measure research productivity in physics are 'results' metrics (lag indicators) which are less appropriate than progress metrics for proactively making strategic and tactical changes within the physics community.

Women in physics

The early loss, from primary school onwards, of women to a physics career or a career that requires substantial knowledge in physics and mathematics has already been described in the section of this report on primary and secondary school education.

According to a report on women in science by Bell (2009)[93] the following problems exist for women in science:

> *"The 'enabling' secondary school subjects of mathematics and science are very important subjects especially when one is contemplating a career in science and technology. Thus, high school education in these subjects is critical as it allows students to prepare for university and ultimately a career in science. In Australia, studies have shown that many female students have not elected to study the more advanced mathematics and science subjects in high school. In addition to the lower participation of girls taking higher levels mathematics courses compared to boys, girls represent less than one third of the students in physics classes, and less than half of students in chemistry classes. However, girls represent almost two thirds of students taking biology classes. This leads to the problem of limiting girls career choices because the subjects studied in high school to a large degree determine what field students specialise in during university studies, and ultimately, their career choices (Ainley et al. 2008[94]; Collins et al. 2000[95]; Jones & Young 1995[96])."*

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[93] Bell, S. Women in Science. Maximising productivity, diversity and innovation. Report for FASTS October 2009
[94] Ainley, J., Kos, J. and Nicholas, M. (2008) "Participation in Science, Mathematics and Technology in Australian Education."

The report argues that the persistent vertical segregation in science and technology disciplines, and continuing horizontal segregation, affect women's capacity to participate, contribute and succeed in 'non-traditional disciplines'. Physics is one such non-traditional discipline. This is evidenced by the under-representation of women in physics globally.

The gender ratio for those studying and working in physics in Australia has remained relatively unchanged (Figure 24) and the status of women in physics in Australia has remained mostly steady until recently with the appointment of several eminent women in major government and public roles. The percentage of girls selecting physics in their final years at school remains consistent (25% of total, but only 9% of girls study physics). A similar but slightly decreasing percentage of women undertake physics degrees at university while the number of males studying physics has increased slightly. Although it is perceived that there has been a minor incremental improvement in the workplace for the number of women working in physics, especially in the university sector, the 2010 staff survey of the university sector for this decadal plan project showed a slightly different picture.

Women physicists are the minority in the university system, which is worsened by more women leaving the university system than entering it in 2010. This indicates that the university sector may have become less attractive to women. However, year-to-year analysis of gender metrics needs to be used to identify if this is a real trend or only a specific event in 2010.

According to Stevens-Kalceff (2007)[97] the career path of male physics academics in a typical Australian university was fairly linear, starting with a PhD and following through post-doc and level A, B, C, D and E academic career stages. Post doctoral research fellowships enhance career progression as they allow the opportunity to establish an independent research profile, produce a critical mass of research publications and provide research networking opportunities. Women physicists typically followed a non-traditional career path which had the following features:

- All women have children and have been/are primary carer at some stage during their career. This has impacted on their career choices and progression.
- Most women took career breaks (3 months - 8 years).
- Some women came to academic physics later in life or as a second career.
- Most women had not done post doctoral/ research fellowships.
- Most women perceived that they spend more time on teaching than research.
- Most women had not taken study (sabbatical) leave. This was sometimes due to issues related to the needs of their partner or their children (e.g. childcare, reluctance to disrupt schooling).
- Some women made career choices based on considerations relating to their partner's careers. These partners were usually older, had not had career breaks and therefore were usually more senior and established in their own careers. The choices made by some women in the context of the "two body problem" might not necessarily be best for their career development/ progression.

In terms of gender balance in the academic sector there is currently a predominance of men in the higher positions above Level A, with the most severe gender imbalance in the highest position levels (Figure 25).

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http://www.dest.gov.au/NR/rdonlyres/46D7FF05 BB9D-4731-A21B-792F2D2E0D8F/24467/ParticipationSMTFINALResMon63Report.pdf

[95] Collins, C., Kenway, J. and McLeod, J. (2000) Factors Influencing the Educational Performance of Males and Females in School and their Initial Destinations after Leaving School. http://www.dest.gov.au/NR/rdonlyres/F0270F6E-B2C3-4CF4-833D-4C8029EA7D6E/4093/Gender_Report.pdf

[96] Jones, J. and Young, D. J. (1995) "Perceptions of the Relevance of Mathematics and Science: An Australian Study." Research in Science Education 25(1): 3 - 18

[97] Stevens-Kalceff. M. et al.: Maximising potential in physics. Investigation of the academic profile of the School of Physics of the University of New South Wales. (2007). December 2007

There is no overall coordination of programs to assist women into the workplace but there is general goodwill. Effectiveness and success in attracting and retaining women in the physics work force appears to be dependent on the local culture, initiatives and attitude of the most senior person in the organisation. Women in all sciences including physics have a lower rate of promotion to senior levels.

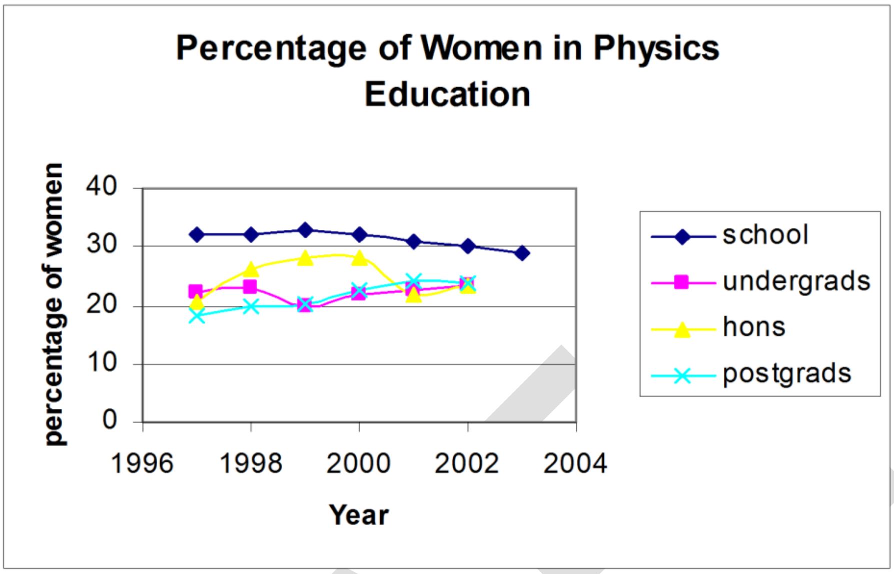

Figure 24 Trends in the percentage of women in Physics education

Source: DEEWR Selected Higher Education Student Statistics 2007; DEST Special Report FTE Staff in AOU Groups 2007

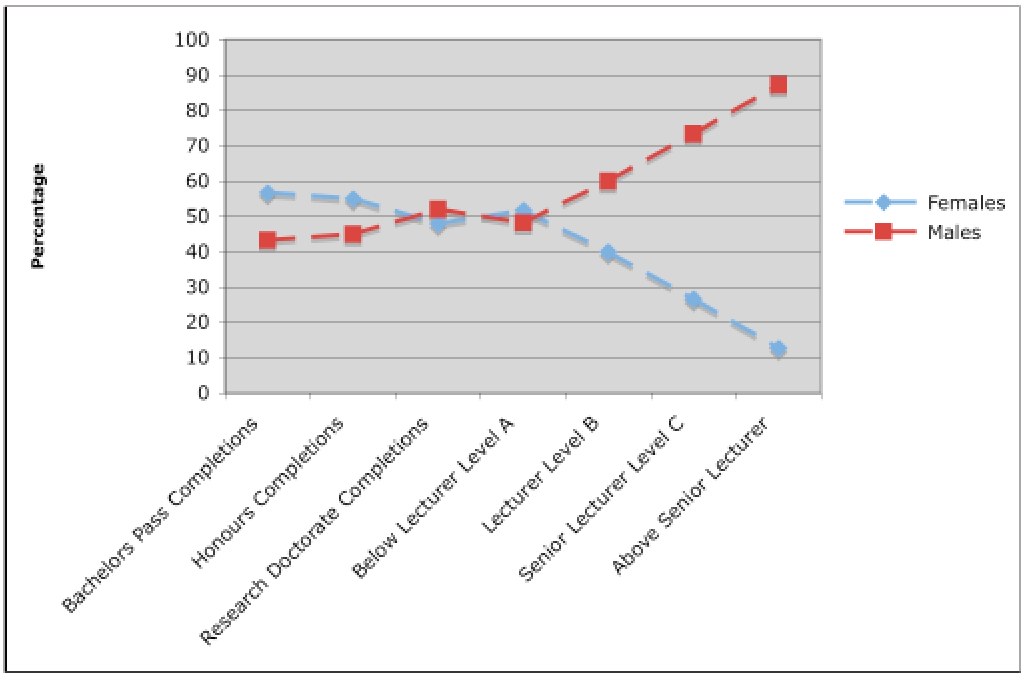

Figure 25 Academic Profiles by Gender; Natural and Physical Sciences 2007

Source: DEEWR Selected Higher Education Student Statistics 2007; DEST Special Report FTE Staff in AOU Groups 2007

The issues of decreasing numbers of women in the higher education and research sector, low numbers of women graduating with a higher degree each year and the gender imbalance in physics performance during primary and early secondary school already cast a bleak picture on a turnaround of the current imbalance in gender proportions in the physics community over the next decade, unless some innovative and drastic measures are implemented. The effective application of ROPE guidelines by funding agencies and employers may be effective in retaining women physicists in the profession and facilitating their career progression into senior roles. The ARC has recently started to report on funding application success rates specifically by gender to alleviate concerns about the application of ROPE guidelines.

In the UK, the Athena SWAN Charter, a voluntary scheme, has been introduced to report on higher education and research organisations' efforts to implement gender equality. The Charter was launched in 2005 and recognises excellence in Science, Engineering and Technology (SET) employment in higher education. Any university or research institution which is committed to the advancement and promotion of the careers of women in SET in higher education and research can apply for membership. The Charter recognises good employment practice for women in UK in SET and is supported by the Equality Challenge Unit and the IK Resource Centre for Women in SET. Member universities and university-linked research institutes and departments can apply for bronze, silver and gold awards. Departments can only apply for a silver award if their university already holds a bronze award. There are currently 35 bronze universities, 11 bronze departments, 40 silver departments and one gold department.[98].

There is also an ethnic imbalance across the physics community. Despite significant growth in Asian migration, there are few leaders in physics, of either gender, who are of Asian descent. However, Australian higher education and research organisations do not routinely report on gender or ethnic minority equality.

Productivity, career paths and metrics

According to a recent report by the Grattan Institute[99],

> *"High levels of productivity and/or high rates of rapid productivity growth are desirable because they enable societies to achieve not only higher material standards of living but also to make other (individual and collective) choices which enhance some of the non-material factors affecting the quality of people's lives".*

The Grattan Institute attributes Australia's deterioration in productivity performance over the last decade, to a combination *"of a dearth of productivity-enhancing reforms (and their replacement by productivity-stifling regulation and legislation); the paradoxically adverse consequences for productivity growth of Australia's extended run of economic success; and possibly a decline (at least relative to other nations) in Australia's take-up of productivity-enhancing technologies."* To lift productivity the institute recommends improvements in education and training, in infrastructure and the innovation effort.

Research productivity is an important contributor to Australia's overall productivity. Although publication output and citation impact is high for the physics discipline as a whole, these two metrics alone are not sufficient to prove high research productivity of individual researchers and the value of the researcher to the innovation system. Additional metrics relating to the impact of the research outcomes in terms of commercial impact are also needed to measure researcher and research workforce productivity.

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[98] Donald A, Harvey P.H and McLean AR (2011) Athena SWAN awards: Bridging the gender gap in UK science. http://www.nature.com/nature/journal/v478/n7367/full/478036b.html

[99] Eslake, S and Walsh, M: Austalia's productivity challenge. Grattan Institute 2011 http://www.grattan.edu.au/publications/069_productivity_challenge.pdf

The recent Productivity Commission's report on research skills outlines the government's priorities for improving research workforce productivity (Figure 26).

CURRENT AND FUTURE PRIORITIES

- Establishment of national research workforce planning processes
- Increased flexibility within current scholarship programs to provide further financial incentives to attract students in demand areas
- Expansion over time in the number of research training awards available to international students

- Review of the RTS
- Examination of the full cost of research training provision in Australian universities
- Development of new models for research training focused on the professional employment needs of graduates
- Establishment and monitoring of research standards and quality benchmarks for research training

- Establishment of a web-based communication platform for research career opportunities and support options
- Review of the balance of fellowship support provided by the Government
- Increase opportunities for early career researchers within the ARC Discovery Scheme

- Incorporation in existing and future funding schemes of supported opportunities for inter-sectoral and international mobility
- Further refinement of processes to remove impediments to individuals returning to the workforce after a career break
- Investigation of metrics for measuring excellence in applied research and innovation

- Removal of impediments for part-time candidature within research training support schemes
- Development and promotion of family-friendly research workplaces
- Implementation of an Indigenous research workforce plan for the higher education sector

SUPPORTING PLATFORMS

- Strengthened oversight arrangements to support improved planning and decision making
- Improved data collection and reporting in relation to the research workforce
- Ongoing investment in the research base

Figure 26 Government strategies for research workforce productivity increase

Source: Research skills for an innovative future – A research workforce strategy to cover the cover the decade to 2020 and beyond. Commonwealth of Australia 2011.

Many of these priorities relate to capturing the full human potential of the research workforce [100].

The report proposes that Australian research students, researchers and research support staff are provided with clear and equitable pathways for career progression and be supported to meet individual career needs and objectives.

The interviews of the physics community for this decadal plan support these propositions. However, existing organisational and work place structures as well as current research career structures will make it difficult to capture all of the human research potential in the innovation system. The lack of participation and the exit of

[100] Research skills for an innovative future – A research workforce strategy to cover the cover the decade to 2020 and beyond. Commonwealth of Australia 2011. http://www.innovation.gov.au/Research/ResearchWorkforceIssues/Documents/ResearchSkillsforanInnovativeFuture.pdf

many women out of the research workforce is one important example for the current lack of effective programs to retain women in the research workforce throughout the innovation system.

In this context, the visibility of career options, employment conditions and opportunities for progression, and national and organisational support structures are all seen as highly instrumental in attracting and retaining research talent.

Currently, there is limited visibility to secondary school students and university physics graduates, of the breadth of potential career paths beside research only. There are limited schemes available that promote science as an interesting, challenging a rewarding career option. Positive examples of such schemes are the national Science and Engineering Challenge and the National Youth Science Forum. However, school students and graduates do not routinely receive information about the likelihood of finding jobs in business and industry and the potential careers they could build and the earnings that they could achieve.

Further productivity losses, besides loss of females out of the innovation system, occur at different stages of the research management process. One important example of process related productivity loss is in shortcomings of the funding application process. The high competition for the few available grants and low success rate within many of the ARC schemes provide substantial barriers for many young people to enter or remain in a research career. Stated figures of 20% of staff time lost annually in the university system for each research staff for the writing of funding applications, including the associated research office administration time, means that there is a productivity loss of close to 20% for each researcher in the university system.

The goal of government to increase researcher mobility into the industry and business sector cannot be supported by using current research productivity and success metrics for researcher quality and excellence. The publication and citation metrics as a measure of quality of individuals and the organisation that trained and employed them are widely understood by the higher education and research sectors as well as by industry. Both the research sector and industry use these metrics to assess the quality of employment candidates. Industry also uses these metrics to assess a research organisation's quality and potential for building collaborative relationships. However, the predominant focus on publication metrics alone and a lack of effective metrics relating to commercialisation and entrepreneurial activity limits the attractiveness of temporary entry of academic sector researchers into industry and business research projects. A consequence of this appears to be that in contrast to key comparator countries and the OECD average, Australia's researchers mostly work in the higher education and research sectors and a significantly lower proportion work in the business sector (less than 30 per cent of all researcher person years of effort in 2008-09).

Industry placement schemes, expatriate return fellowships and funding to assist in building collaborations across institutions and sectors, both within Australia and in other countries, will not find acceptance by researchers if they are not strongly supported by the inclusion of relevant career enhancing metrics in addition to pure publication based metrics.

Currently most metrics at the higher education and research organisation level, particularly at departmental levels, focus on financial and budget management (income including grant income, expenditure), operations and productions (logistics of delivering research and teaching services, and results metrics such as production of research outputs, graduates and postgraduates, Nobel laureates etc) and sales and marketing (number of papers published in international journals, number of overseas students and staff captured) etc. Results metrics related to commercialisation income are predominantly lag metrics and therefore limit the agility and adaptability of the research enterprise.

Current metrics collected for ABS databases and statistics for the FOR codes for "Natural and Physical Sciences" gives research organisations and physics departments only limited ability to be proactive in decision making and adapting to future challenges. Such metrics limit the ability of research organisations and physics departments to:

1. Develop medium to long term strategies that are based on sound analytics of trends, competitors and other data;
2. Monitor implementation of medium to long term strategies and effectiveness of deployed tactics;
3. Develop new products and services to attract and maintain customers (students, industry clients, collaborators, funders etc);
4. Plan and manage their workforce in the medium and long term and increase equity, staff capabilities and at the same time support individual career aspirations;
5. Plan and manage infrastructure resources for the short, medium and long term;
6. Manage risks;
7. Manage the brand of physics as a profession and successfully market the profession; and
8. Manage organisational and departmental managerial capabilities.

This lack of more sophisticated progress metrics provides substantial limitations for Australian higher education and research organisations to pursue revenue growth and proactively to attract diversified funding sources and plan and develop long-term collaborative relationships with national and international research and industrial partners.

ANALYSIS AND DEVELOPMENT OF RECOMMENDATIONS

Drawing on the background research and physics community consultation and survey information, two major Strengths, Weaknesses, Opportunities and Threats (SWOT) analyses were completed during workshops held by the Decadal Plan Working Group. One of the SWOT analyses addressed the general physics landscape and the other specifically addressed the research landscape.

The results of the SWOT analyses and the detailed physics sub-discipline consultation reports (Appendix 8) were used to identify opportunities that clearly address the Critical Success Factors (CSFs) that are essential for each of the physics community sectors to achieve a high level of international competitiveness. To ensure that these opportunities can be realised, a number of recommendations were developed, including options for potential activities for implementation.

SWOT analysis of the Australian general physics landscape

The strengths indicate that Australia's physics research is at a globally competitive level (Table 50) but there is room for improvement towards global leadership in most other aspects of the physics community's operations. The number of weaknesses in the systemic processes and interactions between the physics community sectors and the number of identified threats to the future health of physics in Australia demonstrates that the physics community is currently not as healthy at a systemic level as its research sector would like to believe. To take advantage of the opportunities that are presented by global trends and to utilise the existing strengths requires a substantial culture change in terms of increased inclusiveness and interaction across all sectors of the physics community.

To achieve effective culture change requires greater support from government in implementing relevant impact metrics and reward systems that drive systemic change.

Strengths

Strengths that can be utilised to take advantages of opportunities
• The global trend of internationalisation of careers allows Australian research organisations to source talent from many different countries and likewise export talent. • Demand for highly trained employees is high; they are valued by industry, business (mainly in geophysics in industry, modelling for government and finance sectors, and for research jobs) and research organisations– however, similar in skills to other countries. In geophysics sourcing of employees from former Eastern Bloc countries is continuing due to their perceived superior theoretical physics and mathematics skills and longer physics training. • Understanding of the universe (origin, evolution and fate!) is increasing – however, it is similar to other countries. • International status is improving amongst scientists, mainly due to high rate of high quality publications. • Research strengths areas in Astronomy, Optics and Photonics, Quantum sciences and superconductor materials.

Table 50 Strengths that can be used to take advantage of trends and opportunities

The strength areas identified by the Working Group mostly relate to research excellence and the strong demand for physics based skills in some industry and business sectors that currently cannot be fully met.

Weaknesses

The areas of identified weaknesses (Table 51), could easily, if not addressed, lead to severe threats in the future to not only the physics based research programs and the research sector as a whole, but also to the Australian economy due to an insufficiently educated skill base. This would present a substantial threat to any attempt to develop and maintain a healthy and competitive high-tech industry in Australia.

Weaknesses in the current physics community operating system
• Primary school teacher education needs to but does not currently include strong science and maths components (recognition and reward for strong science skills are lacking and are not considered in recruitment and retention policy). • Secondary school physics and maths teachers should be trained at a level three years higher than the level they teach. This is currently not the case. Countries such as Finland and Russian Federation have a higher focus on subject training). • School students are not sufficiently aware of the relevance , applications and career opportunities that use physics qualifications as a springboard to see the study of physics as a promising career choice (Germany, for example, has a high track record of creating high numbers of physics graduates who find employment in industry, especially in the manufacturing industry). • School students are not interested in studying physics at school or lose interest in physics prior to having to make course choices for the final two years of secondary school. • Students who are appropriately qualified wanting to study physics in Higher Education in Australia are not available in large enough numbers to meet the requirements of the higher education & research sector, the teaching profession and of industry. This has a negative knock-on effect on all of these sectors. • Excellent and inspiring physics teaching at higher education institutions will not be available in sufficient numbers in the future due to the baby boomer academic generation retiring and insufficiently high numbers of replacements being available. • Job security is a major problem for retaining talented researchers in academia and research institutions and providing continuity in large research programs. • Trends towards shorter career segments and several careers in a lifetime (difficult to move between roles in physics). • Lower number of females choosing physics classes in high school and as tertiary courses and careers. • The inwards focus and perceived lack of vibrancy in the research community is seen as declining and threatening the generation of new ideas and creative thinkers. • There are apparently undifferentiated education offerings between main universities, limiting incentives for students and postgraduates to move. • Decreased scientific skills of science journalists/reporters. • Government funding agencies may perceive a low return on investment (relative to other investment options) due to predominant focus of the research sector on publication output and low focus on economic impact factors. • Low focus on research impact factors is defined as a weakness in terms of low effect on improving productivity/economic wealth, employment and country competitiveness that can be attributed to funding of research. • Access to home grown IP that improves industry competitiveness and profitability is restricted to the low number of IP items produced within Australian research organisations. Industry currently needs to rely on overseas IP for in-licensing. • Industry can access research assets globally and avoid investing in own research infrastructure. Currently Australian industry does not see Australian research organisations' research capacity including infrastructure automatically as their best option for solving difficult problems. • The standing of Australia in the international community is weakened because Australian research groups cannot easily access other countries' capabilities, as for this, high powered expertise and collaboration is required and infrastructure that allows other countries to leverage their own infrastructure and research investments.

Table 51 Weaknesses in the current Physics community operating system

Threats

The list of existing threats to the Australian physics community is already substantial, based on a large number of global trends and existing systemic weaknesses in the Australian physics community (Table 52). However, many of these threats and global trends also provide opportunities for Australian physics. More importantly, action needs to be taken to address some of the more serious threats in order to at least neutralise or mitigate their potential negative impact on the physics community and the Australian economy (Table 53).

Threats to the current physics community operating system
• Interest rates, exchange rates, decrease in disposable incomes and higher food prices will have a downwards effect on domestic and international student numbers and a switch of destinations to countries with lower fees and/or more favourable exchange rates. • Rising economic power of 'Asian Tigers' and other countries in the Asia Pacific region will lead to higher investments into their own higher education and research infrastructure and talent generation, leading to a decline in international student numbers from the Asia/Pacific region studying in Australia. • Reduced influence of US and power shift to China will lead to new shifts in collaborations with and investments in China instead of in the traditional research intense countries. • Developing nations (e.g. China, India etc..) and oil-rich nations (e.g. Gulf States) re-focus from exploitation of natural resources to higher education and innovation, leading to talent drain out of Australia into these countries and reduced international talent pool for Australian research and academic positions. • Western economies will continue to struggle economically and will have limited success to entice industry and business to increase spending on R&D. This may lead to reduced IP outputs and reduced demands for physicists in industry and business. • The scientific gap between the currently leading countries and emerging nations in terms of research outputs and patent applications is closing. For Australian physicists to remain competitive on a global scale, critical mass and excellence of research and infrastructure are necessities and declines in either pose a large threat. • Over-reliance on exploitation of natural resources in Australia and exporting of low value-add commodities prevents re-focusing on creating alternative sources of economic wealth through innovation. • Increased protectionism and subsidies in some countries to protect their own home-grown industries may lead to faster technology development in these countries in comparison to Australia. • Increased efforts to compete in education ranking tables by most countries leads to increased effort and spending and the danger of Australian institutions dropping down in ranking tables and falling below OECD average in critical innovation indicators. • Can't rely on the 'Voice of science' being heard or understood by political decision makers. Political decisions based on intuition and potential attractiveness to voters provide unpredictability and focus on short term fixes and funding. • The link between national priority areas and the research funding budget that determines where physics is done in Australia is vulnerable to political trends. • Physics curriculum specifications in schools and higher education is increasing in Australia and if the bar is set too low the impact is negative for all downstream sectors. • Legislation is making Australia unattractive to networked global industry in terms of innovation speed and cost, e.g. R&D tax and business investment compared with other countries. • High population growth and food and water security issues lead to political unrest and low priority for education and R&D in these countries coupled with a need for additional aid funding and defence spending (especially in developing nations). This leads to reduced availability of international students

in Australian higher education institutions.

- Ageing demographics in developed countries and health issues due to lifestyle and diet lead to higher health care expenses and downward pressure on education and research and innovation spending.
- Ageing academic workforce in Australia may leave a gap in skills with a knock-on effect on downstream sectors.
- Gen Y not willing to move to study and/or work in locations other than their home location which may lead to a limited generational talent pool for industry and the research sector. It will also lead to further inward focus of the physics research sector if exposure to outside ideas is limited.
- Growth of consumerism in emerging economies leads to focus on buying new things rather than on education.
- Decreased trust and respect of science and its complexities and divergent views by the Australian population leads to a belief that science and physics is not needed.
- Increased urbanisation and decline in investment in regional Australia reduces accessibility of higher education and research & development careers of the regional and rural area population.
- Shortage of STEM professionals in schools and industry as other careers more attractive.
- Instrument manufacturers building instruments and medical devices that increasingly do not need physicists to maintain and monitor them for functioning (medical imaging, radiotherapy etc.) may lead to reduced numbers of medical physicists.
- Increased impact of more frequent and severe adverse weather events with higher insurance and rebuilding costs will put downward pressure on government, business and private spending on education, and research & development
- China's R&D position through investing in R&D will keep growing, with China's research infrastructure becoming globally competitive for other countries to utilise instead of Australian infrastructure.
- Increased investment in the US and Europe in academic institutions is being matched in emerging and transitional economies in order to become competitive to US and European institutions. Australia does not feature on the competitive chart of potential competitors.
- Scientific collaborations between global technology leader countries and emerging nations will lead to increased competition between the collaborators later, potentially leading to loss of Australian industry segments if focus does not change towards building a high tech industry in Australia.
- "Greening" of national research and innovation strategies in OECD, BRIC and other countries provides more funds and focus for environmental science, not physics.
- Related disciplines (e.g. engineering, chemistry, biology) avoid physics service teaching from physicists and prefer using their own talent to teach physics (due to current funding models).
- Excellence of research infrastructure and resources in Australia to attract research talent is threatened by low focus of government on spending on infrastructure updates and maintenance.
- Commercialisation capability in Australia is lower than in other technology leader countries, demonstrated by Australia's low patenting record with impact on all downstream segments, and on the number of new to the world products and services. This threatens the speed of innovation in Australia in comparison to leading countries in the area of commercialisation.
- Low predictability of funding to attract and retain talent and take research risks that don't depend on short term funding cycles leads to focus on "safe" research that leads to scientific publications.
- The science and physics knowledge of the general population is too low to better participate in current debates, and fully accept and understand the benefits to society of higher education in physics for the creation of beneficial physics research based IP and technology.
- High level of education for Australian children is threatened (see declining PISA and TIMSS results) as other countries have a higher focus on achieving high PISA and TIMMS ranking to boost their overall education standards.
- Ability of the international community to address bigger questions that can't be solved in isolation with the help of Australian high quality education & research expertise is threatened if focus on excellence is reduced.

Table 52 Threats to the health and operating processes of the Physics Community

Opportunities

Opportunities present themselves based on the global trends, particularly with the power shift from west to east, with Australia advantaged by its geographic location, the high quality of its education and research sector and research infrastructure.

Strengths will need to be leveraged and weaknesses will need to be addressed in order to capitalise on the many opportunities that exist for all the physics community sectors.

Opportunities for the physics community and their individual sectors
• Economic conditions and low unemployment in Australia make it attractive for academic/research staff attraction from other markets. However, it has to be ensured that the new talent comes from technology and research leading countries. • Rising wealth in countries such as China create demand for higher education and research training for established providers in Australia providing they maintain their ranking and excellence levels. • The global population is increasing and the level of education internationally is also increasing with more demand on higher education providers at the top edge. • Ageing demographics in developed countries and health issues due to lifestyle and diet lead to higher health care expenses and downward pressure on education and research and innovation spending. This leads to higher requirements for trained medical physicists etc. • Immigration trends and related education requirements require more places for higher education as Australia is perceived as attractive for immigrants who highly value education. • Increased mobility in all countries leads to more students becoming available for studying in Australia, provided that Australian physics education is comparatively better than in their home countries. • Growth of consumerism in emerging economies leads to higher requirements for technology IP. • Western economies will continue to struggle economically and will have a greater need for innovation and new product and service development. This will require the increased involvement of physicists as they have proven to have a high impact factor in innovation and successful new product and service development (at least in Germany). • Increased shift to internationalised tertiary education leads to increased needs for international talent for Australian higher education institutions. • Growth in international student numbers studying in Australia has been greater than for domestic students, providing a solid basis for planning towards expansion of physics departments in higher education institutions. • Personalisation of products and services: A trend towards 'personal touch' and growth of the services sector based on innovation in technology that supports the services sector requires physicists who are proficient in applied physics and at the interface with engineering. • iWorld: Digital and natural world convergence and expansion of the internet will lead to a greater need for physicists trained at the interface of a number of disciplines. • 'Greener' (lower carbon footprint, less waste etc..) technology products will require physicists in both fundamental and applied research and industry R&D teams. • The trend to smarter materials (e.g. super conductors) will require more fundamental and applied research and physics based R&D talent in industry teams. • Depletion of natural resources combined with increased demand leading to a need to do more with less. There will be a need for more resource efficiency and therefore a need for more physicists in the energy sector. • Climate change requires new technologies for research, modelling and prediction of systemic changes and their impact in both the atmosphere, on land and in the ocean environment. This will require new measurement instruments, more advanced super-computing powers and development of models. Physicists are a key resource in these areas. • Shortage of carbon based fuels will require development of new power generating systems that are

not carbon based and physics will play a large role in this endeavour. • Increased demand for renewable/sustainable energy, given the current tendency away from nuclear power requires the input of physics research and development. • Increased requirements for environmental clean-up and remediation technologies requires physics skills in materials and condensed matter physics. • R&D spending increases in the Asian nations is forecast to grow at rate multiple to that of advanced economies and could lead to increased influx of highly skilled talent into Australian R&D teams both in research organisations and industry. • Continued globalisation of research will lead to decentralising of large industry companies' R&D organisations and investment in and building of decentralised facilities in off-shore locations. Provided Australian research teams/infrastructure are seen as more attractive compared to other destinations (taking the distance and small market size into account), this is an opportunity for Australia to attract external research funds. It will require active steps by the Australian physics community to engage with international industry. • Curriculum specification in schools and higher education is increasing (in Australia). Provided that physicists can have a guiding input into the curriculum, the curriculum can be made attractive to Australian school students. • Delivery of a high standard physics curriculum by teachers with a tertiary degree in physics and/or mathematics will ensure that more school students will receive appropriate physics qualifications for entry into tertiary education and to meet future needs of employers. • Easily accessible and up to date information for physics graduates on potential employers and employment sectors that have a track record of employing physics graduates will allow graduates and postgraduates to reduce the time gap to employment. • The development of a united professional image that promotes the importance of both fundamental and applied physics to drive innovation in industry will have a positive impact on both employment opportunities and career paths of physics graduates and innovativeness of industry. • The development of a "career description" for typical physics career paths will ensure that school children, their parents and graduates have a clear picture of some of the physics career possibilities to help in their decision making process to choose to study physics. • The development of transparent and equitable metrics and reward systems that measure and reward excellence at all stages of the innovation continuum from fundamental research, applied research, teaching, entrepreneurial activity to working in industry research will increase the likelihood that people with the highest skill levels in each of these areas are retained in and attracted to Australia. • Introducing effective mechanisms for facilitating exchanges of high calibre researchers between research organisations and industry that will not penalise career prospects, will invigorate mission based fundamental and applied physics research in research organisations and increase the innovative power of industry companies. • Reaching agreements between sub-disciplines on mechanisms that demonstrate that the physics community is becoming inclusive of the sub-disciplines already split off into their own communities (e.g. geophysics and medical physics), the newly defined sub-disciplines (e.g. econophysics, neurophysics, psychophysics etc.) and the more applied sub-disciplines (e.g. photonics and optics) will revert existing inward focus and foster cross-sub-discipline research. • Increasing collaboration between universities in the same location (e.g. capital cities and close by regional centres) will fill gaps in teaching and increase the depth and breadth of undergraduate education and honours degrees at the second and third tier universities and in sub-disciplines with low student numbers

Table 53 Opportunities for the Physics community and its sectors

Trends and SWOT analysis of physics research

There are a number of global trends that provide opportunities for Australian physics science and research, given the existing strength areas and already evident accomplishments. The following trends and SWOT analysis provides the basis for the science based recommendations in this report.

Trends in physics science and research

The cluster chairs and their advisors identified a number of global trends that are currently evident and that will have an impact on research in the next decade. They are summarised in Table 54.

Global trends in Physics science and research
• Condensed matter physics will increasingly rely on sophisticated materials processing and characterisation tools. • All research is moving towards a large scale in terms of technologies and number of people required that is well outside the context of Australian universities. • Emergence of an accelerator science community in Australia (incl. the Australian Synchrotron) linking with international partner communities incl. CERN and KEK. • There will be increasing overlap between particle physics and astrophysics/cosmology on the themes of dark matter/dark energy • Emergence of burning plasma fusion science. • Plasma physics will have higher focus on applications. New applications are plasma chemistry and medical applications of plasmas with potential for plasma sterilisation in the food industry and in medicine. • Trend to commoditisation and more convenient availability of super-computer resources and associated software will allow researchers to work on larger, more sophisticated problems without needing to become experts in computation • The impact of new super-computer facilities is likely to be significant in the future as researchers seek more accurate models for physical systems at the atomic, molecular and integrated device level. • Traditional Australian strengths in materials for microelectronic devices and photonics will be a strong feature continuing at least into the next decade. • Nanowires as the next building blocks for the next generation electronics and photonics. • In chemical physics: *Ab initio* quantum mechanical calculations of materials, mostly liquid, gel and solid/glass phases. • In chemical physics: Atomic, molecular and macromolecular scale design and engineering of materials, from host-guest materials (e.g. gas storage as fuel cells) to biological nano- and meso-scale assemblies (from protein-substrate complexes to cell organelles). • In chemical physics a major and continuing trend is the understanding of materials structure and performance at larger length scales, beyond the A-scale, to 1 – 100 nm. • Trend towards fibre-based laser and delivery systems. In the future the continuing reappraisal of quantum mechanics for its applications to technological devices will be a strong theme for Australian researchers. • The convergence of quantum optics and condensed matter physics enabled by nanofabrication. • Nano-indentation based phase change memories, resistive memories based on dielectric films are emerging areas of research. • The frontier of photonics globally and nationally is in nanophotonics. • In optics/photonics a shift towards nano-scale techniques and technologies. This will place greater demand on national fabrication infrastructure, while increasing the need for more local facilities for researchers. • Quantum dot solar cells, nanowire solar cells and plasmonic solar cells will have greater potential to make a major impact on future photovoltaic technologies. • The big trend in photonics, integration and nanophotonics are to use lithography to produce circuits and devices. CUDOS is now entering the paradigm of integration • The trends in biophysics are going towards biomaterials, bio-energy, bio-fuels, artificial photosynthesis and chemical systems. • There is a growing importance of the interface between the life and the quantitative disciplines. • Trends in biophysics are concerned with the development of biomaterials, bioelectronics for real time

diagnostic health systems. The development in this area is very promising and fast. • In optics/photonics a trend towards cross-disciplinary research, physics research brought together with materials science, chemistry, biology in any combination. • Nuclear interactions with biological and physical matter as there is a huge number of questions of a profound nature from understanding radiation damage in tissues to understanding big systems phenomena, cosmic generated radiation and its impact on the biosphere. • In nuclear physics internationally (Europe, Japan and Korea), major new facilities are being planned with a focus on rare ion accelerators – major interest is in nuclear astrophysics, understanding the formation of elements and their abundances. There are also plans for further high energy electron machines. Australia could be left behind if it does not monitor international trends • The focus is shifting from remote sensing using field stations to computation (possibly due to reduced funding availability) resulting in the growth of climate modelling at the expense of climate physics looking at the fundamental drivers. • The global imperative to address issues in climate science is likely to see larger research programs arise in the study of materials for alternative power and energy efficiency to develop alongside the already large programs in silicon photovoltaics • There is concern about the impact of space weather on modern technology with a recent American Academy of Science study report predicting a possible 30% shut-down of the US power grid if a solar storm of the magnitude experienced in 1921 re-occurred. • Smaller and cheaper instruments for accelerator mass spectrometry (AMS). • In nuclear physics the development of smart detection technologies leveraging electronic and computing advances. • In nuclear physics the development of techniques for ultra-sensitive measurements using accelerator mass spectrometry (AMS) for applications in resource exploration, water management, archaeology, climate change and in the pharmaceutical industry.

Table 54 Trends in global Physics science and research

Research strengths

There are many areas of research that illustrate that Australian physics research is currently very strong across several areas, in particular astronomy and space science, optics and photonics, quantum systems and computing and related condensed matter research and superconductivity (Table 55)

Strengths in Australian physics research and science
• One of the great strengths is the field of astronomy and space science. • Particle physics in Australia has recently received a massive boost through funding of the ARC Centre of Excellence for Particle Physics at the Tera-Scale for the period 2011 to 2017. • Globally competitive research strengths exist in Engineered Quantum Systems and in Quantum Computation and Communication Technologies (CoEs, e.g. ARC Centre of Excellence for Quantum Computer Technologies). • A current lead exists in the area of space plasmas that gives a platform for engagement with international space programs. • In Australia there is world competitive research in superconducting technology, semiconductors, quantum computing, photonics and photovoltaic systems (e.g. ARC Centre of Excellence for Quantum-Atom Optics). • Optical physics in Australia is healthy, thriving and strong. Strengths span from theoretically focused research to optical materials to micro- and nanofabrication and device development. A key strength is the degree to which these elements work together effectively. Australia's competitive advantage in optics/photonics comes from the fact that it is approached from the photonics/technology background rather than from the atmospheric research field as is more typical internationally. • Biophotonics in the broader sense of integration into optics and laser communities, nanophotonics, in

situ bio-imaging and spectroscopy are gaining strength in Australia.

- Some of the most important areas of growth within optics are nano-optics, plasmonics and communications.
- In the area of physics meeting applications in optics, Australia has global capabilities. This is especially so in communications, with the development of nanoantennas, the development of single photon sources has been very promising.
- There are strengths in "extreme" remote sensing but there is limited visibility of this area of strength within the optical physics sub-discipline.
- Organic opto-electronics is a research strength at CSIRO, UQ and the University of Newcastle.
- The ARC Centre of Excellence for Ultrahigh-bandwidth Devices for Optical Systems demonstrates an area of research strength.
- The ARC Centre of Excellence for Advanced Silicon Photovoltaics and Photonics is an area of research strength.
- The ARC Centre of Excellence in Antimatter – Matter Studies demonstrates and area of research strength.
- Ion beam modification of materials for a range of applications is an area of strength with excellent ion beam analysis of materials expertise and capabilities.
- Nanowire research is an area of strength with the aim to develop devices for energy, sensing, electronics and photonics applications.
- III-V semiconductor based quantum well and quantum dot optoelectronic devices is a major area of research strength.
- The ARC Centre for Nanostructured Electro-materials demonstrates an area of research strength.
- The ARC Centre for Functional Nanomaterials demonstrates an area of research strength.
- The ARC Centre of Excellence in Coherent X-ray Science demonstrates an area of research strength.
- In energy and power technologies a number of research groups have critical mass and are now about 200 people including PhD students, including a planned "Energy Change" institute. Strong connections to companies in Asia, leading to R&D opportunities and prominent commercialisation programs.
- The ARC Centre for Solar Energy Systems demonstrates and area of research strength.
- The Hypersonics scramjet program is one of a limited number of international research programs in this area and is having an international impact.
- The ARC Centre of Excellence in Design in Light Metals demonstrates an area of research strength.

Table 55 Strength areas in Australian Physics science and research today.

Research weaknesses

Areas of research weakness relate mainly to insufficient depth in selected research fields, lack of critical mass, barriers to interdisciplinary research, funding and commercialisation process issues as well as potential issues in postgraduate education (Table 56).

Weaknesses in Australian physics science and research

Depth issues

- In quantum science in research into neutral atoms, ion traps, superconducting circuits, opto-mechanics, photons, quantum dots – the real issue is depth.
- Soft matter, especially colloid, polymer physics, physics of disordered solids – structural, thermo-dynamical and statistical properties have never been strong in Australia.
- Collectively, organic opto-electronics is mostly populated by chemists. Organic electronics has emerged from material science, chemistry and chemical engineering departments and is not grounded in soft matter.
- Biophysics in Australia, if viewed narrowly as being concerned with ion channels and electrophysiology of membranes, is strong, but when viewed more broadly it still has a way to go.

Lack of critical mass

- In optics and photonics lack of good semiconductor fabrication facilities nationally is a weakness.
- Climate and atmospheric physics has not been strongly represented in universities with much of the research now based in the Bureau of Meteorology and CSIRO (research training issues).
- As classical physics (e.g. acoustics) can be done well by small groups with little infrastructure, it has lacked support from funding bodies who aim for 'critical mass' and big infrastructure projects.
- In advanced teaching programs in theoretical physics, because of the small student numbers at individual institutions and the concentration of expertise in few institutions teaching of theoretical physics is difficult in many institutions.

Postgraduate education

- The two ARC Centres of Excellence CQC2T and EQUS capture most of the Australian research excellence in quantum control and quantum information and may enable Australia to address the hopeless state of postgraduate education in quantum physics.
- In particle physics the postgraduate cohort in any one institution is too small to make postgraduate coursework economical.

Barriers to interdisciplinary research

- The currently widespread perception that CSIRO tackles interdisciplinary work well ignores the fact that much larger research capacity exists within the higher education sector than within CSIRO that cannot engage as readily in such work due to counter drivers.
- There are systemic difficulties in universities collaborating with CSIRO, DSTO, ANSTO etc.
- Interdisciplinary science is not adequately supported under the current funding schemes. For example, obtaining funding for medical physics is difficult as physics and medicine have different funding bodies. There is no identified funding mechanism for involvement by Australia in large collaborative international research projects that require significant funding on a short time scale.
- The limit of just two DP grants per person is a serious restriction and limits outcomes. One serious impact of this is that it, in itself, limits interdisciplinary research because none from another discipline can afford to give one of their 'slots' to support a grant for someone in another discipline.

Funding process issues

- Extreme dependence on ARC grants with low success rates leads to interruptions in the continuity in funding.
- The major issue of manpower and competing efforts spent in education and on the shear amount of time spent in applying for and reporting on grants leads to less time spent on the core function: research.
- Outstanding performance by international standards does not guarantee funding by Australian funding schemes.

Commercialisation

- There has been less impact of Australian research on the global semiconductor industry, perhaps because this industry is often sited where it gets the largest tax concessions and this has not been Australia. This may be why Australian work in this field is on a smaller scale than is frequently the case in the USA and Europe.
- In nuclear physics there is low appreciation of the significance of multidisciplinary spinoffs and applications possible from techniques such as accelerator mass spectrometry.
- Judging the individual impact of Australian researchers is difficult. Lack of visibility of impact is revealed by patents that cite Australian papers. The situation is similar in photonics where Australian researchers had some leadership roles.

Table 56 Weaknesses in Physics science and research

Research threats

The threats identified by the subject matter experts largely reflect the issues already identified in the general physics community interview process (Table 57). These threats are generally not specific to physics research or science, except perhaps the relationship between sub-disciplines.

Threats to Australian physics science and research
Careers • The time between PhD and ongoing appointments for those who do receive one is much too long and is a big disincentive for young people contemplating a career in science. • Currently an academic career in physics is not a good prospect for bright students – 4 years PhD, several postdoctoral positions, and then a slim chance of a permanent position. It is not worth trying to make physics attractive to bright students if they have no career prospects. • Limited career pathways and not just for academics. • The lack of ongoing research only positions in universities limits research. • The small numbers being attracted to the field of nuclear physics is severely limiting the ability to take advantage of new opportunities, related to the decreasing size of the student cohort studying physics. • Rapid decline in the number of tenured staff at most institutions over the last 20 years is threatening physics in Australia. Student-staff ratios have risen dramatically.
Negative effects of competition between disciplines and between physics sub-disciplines • Due to existing university funding models, university physics service teaching for other disciplines such as engineering and medicine is increasingly been done by that other discipline. In major US universities, service teaching is the mainstay of physics department budgets, allowing a large permanent staff with considerable research time. Physics service teaching should be protected to ensure students are taught by discipline experts.
Perceived lack of representation on international agencies • There is lack of representation of Australian agencies such as ARC/DIISR on Boards of major international projects or on OECD working groups – the role played by DoE or NSF in the USA and European funding agencies.
Perceived lack of coordination and strategic approach in Australian research management and planning • There is an uncoordinated approach to management of research in Australia to ensure the health of the discipline of physics • Emerging research at present often falls between the cracks in the ARC panel-base funding system, and this problem has been exacerbated by the introduction of ERA. • Uncertainty about the future funding of the National Acoustics Laboratory is a cause for concern.

Table 57 Threats to Australian Physics science and research

Research opportunities

The cluster chairs and their advisors unearthed a multitude of scientific opportunities for the next decade. Many of these opportunities will require the collaboration between Physics sub-disciplines and other science disciplines (Table 58).

Opportunities for Australian physics science and research
Large infrastructure based collaborations • LIGO-Australia will have significant spin-offs in relevant physics and technology, including advanced detectors, optics, lasers, vibration isolation, feedback control, vacuum systems, data handling, and computational physics. It will also allow a dramatic increase in the number of researchers and students in the field of gravity wave research in Australia and linkages to the international community of more than 1000 scientists in this research field. • The further development of accelerator science for the ARC Centre of Excellence for Particle Physics at the Tera-Scale provides opportunities to engage with the high energy astrophysics community. • Large scale accelerator facilities for radioactive ion beams are being built around the world to provide exotic nuclei far from stability with a range of applications. Australia needs to develop collaborations that allow engagement with these facilities. • The $25 million of new facilities at ANSTO and the $10 million upgrade of accelerator facilities at ANU and the University of Melbourne will create opportunities for interaction with other universities, CSIRO and industry. There is potential to develop new applications for accelerator mass spectrometry e.g. Chlorine-36 is of interest to the groundwater community, may be of interest to the seam gas and oil industry and uranium-236 is of interest as a prospecting tool. Biomedical applications are possible and will need cross-disciplinary teams. • Development of new techniques to make complementary measurements on Australia's stable beam accelerators represent the best opportunity for entry into international collaborations. • Linking to ITER offers opportunities. New applications are plasma chemistry and medical applications of plasma. Both have great potential. **Optics and Photonics** • Future opportunities in optics/photonics lie in projects focused on developing new instruments that push the limits of measurement (in particular enabling the detection of new gases in the atmosphere, or longer range performance or broader wavelength operation. • Emerging synergies of optical physics lie in surface science and the “omics” • This is the “era of materials”, especially for those with applications in microelectronics and photonics which have seen spectacular evolution with no end in sight over the next one or two decades. • The capacity of emerging optical devices to measure biomolecules or chemicals within nanoscale volumes, the ability to image on the nanoscale and for real-time and/or continuous measurement have the potential to make a big impact in health, defence and the environment. • The frontier of photonics globally and nationally is in nanophotonics. Exciting opportunities exist when photonics, integration and nanophotonics are brought together. • Potential for the Institute in Photonics and Sensing in Adelaide to overlap with experimental particle physics – radiation resistant equipment and detectors, getting light signals out of equipment in this environment. **Interdisciplinary research** • Increasing opportunity for working with researchers from other disciplines to create new measurement tools where the end outcomes include an enhanced ability to do research in other disciplines (e.g. Health research). • There is a vast increase in the amount of data in biology in the form of images that require sophisticated image processing and data analysis techniques that could be supported by better collaborations with physicists. • There is opportunity for acoustics physics research to support biologists researching animal sound production and hearing, as well as for example, the aeronautical industry in the detection of damage to aviation components. • At the biology interface, physicists have a role in identifying how to deconstruct a problem into its

component parts. This skill is important in new problems at the frontier of physics and biology including nanoscience and neuroscience.

- There are opportunities in the traditional physics areas that employ advanced instrumentation that will be increasingly important at the boundaries of physics and biology.
- The sub-discipline of acoustics has particular capacity for reaching across to other disciplines (health, defence, and environment) to create new technologies and solutions including "disruptive" technologies.
- The study of condensed matter will expand to model the neural networks of the brain on both spatial and temporal scales.
- Soft condensed matter physics in Australia is currently not driven by physicists. Internationally that is not the case, for example groups in the UK and Germany train the best researchers in this area. There is a massing opportunity for Australia to capitalise in this space.
- New biomaterials are emerging from soft matter physics. Soft matter physics has a great role to play and this is where the field is currently moving.
- Interdisciplinary work with biologists on interactions of plasma produced ions, radicals and excited atoms and molecules with cells in plasma sterilization.
- Quantum information approaches have great potential to solving basic problems in chemistry, material science and biology and enabling new science which up to now has been stymied.
- A significant challenge for the future is to explore quantum coherences in photosynthesis that has very significant applications for revolutionising our understanding of the role of quantum mechanics in biology and potential industrial impacts.
- There is a new field of research that has emerged strongly in recent years at the intersection of physics and biology: measuring quantum states in living cells, brains, neuroscience, and photosynthesis – the next big application of quantum mechanics to real systems.

Energy applications

- There is opportunity for major developments in materials for photovoltaics, fuel cells and other energy applications along with advances in sensing, environmental monitoring, biosensors and more.
- There are unmet innovation needs in battery research, which requires strong collaborations between physics and materials chemistry, and also solar energy.
- There is opportunity to design and model the future energy systems and how they will look and how the grid would look in 20 years.
- Use of plasma for PEM fuel cell production.
- Application of atmospheric pressure plasmas in conversion of waste to syngas.

New measurement and detection technologies

- In nuclear physics Australia is able to compete in the development of smart detector technologies and modelling as they do not require large investments in infrastructure.
- In nuclear physics, development of new detection technologies for mineral and resource exploration, increased efficiency of industrial processes, security and medicine could provide Australia with a competitive edge over others.
- Development of new techniques to make complementary measurements on Australia's stable beam accelerators represents the best opportunity for entry into international collaborations.
- There are opportunities in the traditional physics areas that employ advanced instrumentation that will be increasingly important at the boundaries of physics and biology.
- Potential for the Institute in Photonics and Sensing in Adelaide to overlap with experimental particle physics – radiation resistant equipment and detectors, getting light signals out of equipment in this environment.
- Increasing opportunity for working with researchers from other disciplines to create new measurement tools where the end outcomes include an enhanced ability to do research in other disciplines (e.g. Health research)
- The capacity of emerging optical devices to measure biomolecules or chemicals within nanoscale volumes, the ability to image on the nanoscale and for real-time and/or continuous

measurement have the potential to make a big impact in health, defence and the environment.
- Future opportunities in optics/photonics lie in projects focused on developing new instruments that push the limits of measurement (in particular enabling the detection of new gases in the atmosphere, or longer range performance or broader wavelength operation).
- Some of the problems of interest at the boundaries between chemistry and physics use tools such as femto-second laser spectroscopy to probe chemical dynamics at the fs timescales. This brings condensed matter physics models into the realm of chemistry and biology.
- For the future to make "molecular movies" to visualise the progress of chemical reactions will be important.
- There is a vast increase in the amount of data in biology in the form of images that require sophisticated image processing and data analysis techniques that could be supported by better collaborations with physicists.

Quantum science

- Quantum information approaches have great potential to solving basic problems in chemistry, material science and biology and enabling new science which up to now has been stymied.
- Opportunities for consolidation of research areas to provide a more unified approach within the new ARC CoE for Quantum computing and communication technology.
- The general problem of "high temperature quantum coherences" is in the same league of difficult problems as the development of a model for high Tc superconductivity that continues to be challenging to solve.
- A significant challenge for the future is to explore quantum coherences in photosynthesis that has very significant applications for revolutionising our understanding of the role of quantum mechanics in biology and potential industrial impacts.

Modelling

- Computer modelling of arc plasmas could improve process reliability and productivity in industrial applications.
- There is opportunity in increasing the capacity to model materials and molecules.
- There is opportunity to design and model the future energy systems and how they will look and how the grid would look in 20 years.

Disorder

- There is opportunity to increase the capacity to model materials and molecules.
- In the very long term the physics community could rise to the challenge of addressing problems in disordered materials.

New fields of research

- Magnonics, a new technology emerging out of the relatively young field of magneto- and spin-electronics, where the domain walls are the active elements. In magnetic metals, the domains and domain walls interact with, and can be controlled by, conduction electrons. The associated phenomena, including things such as spin transfer torque and spin wave oscillators, are opening possibilities for entirely new technologies for low power information and communication technologies. Around ten groups in Australia, often located outside traditional physics departments, address these issues.
- There is a new field of research that has emerged strongly in recent years at the intersection of physics and biology: measuring quantum states in living cells, brains, neuroscience, and photosynthesis – the next big application of quantum mechanics to real systems.
- New challenges are arising from the use of strained layers and understanding defects. An example is the emergence of "III-V" materials with applications to photovoltaics.

Table 58 Opportunities in Australian Physics science and research

Sub-discipline needs

Based on the global science and research trends in physics and the opportunities, a number of sub-discipline specific needs were conveyed to the sub-discipline cluster chairs (Table 59). These needs were further summarised in the physics sub-discipline cluster reports (Appendix 8) for inclusion into Part 1 of this plan.

<table>
<tr><th>Sub-discipline specific needs (in no particular order)</th></tr>
<tr><td>

There is need for greater sophistication, focus and funding for optical materials science research to underpin both basic research and a wide range of device platforms for applications.
In order to lead the science in photonics, integration and nanophotonics, the current level of funding has to be maintained. In optics and photonics generally substantially more work will be needed in areas of imaging, quantum imaging, spectroscopy and sensors.
In optics and photonics we need a more dispersed model for the allocation of research infrastructure combined with good access models.
In optics and photonics some of the greater challenges are arising from the need for highly skilled technical staff who are difficult to support with current funding systems.
In quantum information and engineered quantum systems sub-disciplines we are going to require access to better and better manufacturing capabilities as well as we will have to be clever in how we use our people as the scale of everything goes up.
In quantum information and engineered quantum systems there is a need for substantial infrastructure in-house and efficient and fast utilisation of it in order to progress projects from an idea to a fully developed device.
In chemical physics the exploration and understanding of material behaviour at the scale of multiple micrometres is a difficult regime due to the very poor theoretical understanding of this length scale, that straddles (“bottom up”) poly-molecular self-assembly and (“top down”) materials design (e.g. via 3D printers or ion beam sculpting).
An emerging bottle neck is in processing of massive 3D datasets, and accelerated parallel efforts to develop sophisticated image processing tools along with 3D data acquisition are essential to capitalise on the explosion of data afforded by modern imaging techniques.
The advent of superior imaging technologies, particularly 3D imaging techniques (e.g. Synchrotron tomography) is crucial to better understanding of natural materials.
In climate physics a mapping of wind fields which can now be undertaken. There needs to be more attention to a more comprehensive field base for observations of, amongst other issues, radiative transfer and atmospheric chemistry and to provide valuable verification data for computer modelling.
In climate and atmospheric physics, while to focus on modelling is important, there is a need for more field stations and fundamental research on the issues of the physics turbulence, radiative transfer, clouds, processes and the ocean / atmospheric interface.
There is increasing need for environmental remote sensing driven by the need for tools to monitor climate change and to support the development and deployment of renewable energy technologies.
To develop low cost, large area reel by reel photovoltaic systems, many materials science issues need to be addressed prior to their widespread use.
Establishment of a major national fusion laboratory, perhaps building on collaboration of ANU and ANSTO.
In medical physics there has been a debate for some years as to whether hadron therapy would be a cost effective adjunct to current technologies. The success of such a proposal will certainly improve treatment in many key areas but to be viable it may need to have other applications.
LIGO Australia would need to commit funding averaging $13 million a year for 15 years for infrastructure, installation and operating costs. The funding would need to come from federal, state and university sources as well as international collaborating partners.

</td></tr>
</table>

Table 59 Sub-discipline specific needs (not prioritised)

A number of needs, common to all physics sub-disciplines, were also identified and largely mirror those identified in the general physics community operating environment interviews, with the exception of the need to engage more with Asian research centres and scientists and optimise engagement with international funding agencies for international large infrastructure and research programs. These needs are summarised in Table 60.

Specific needs common to all physics sub-disciplines
• There is a need for a mechanism to access EU funds.
• It should be ensured that we have the right teaching offerings to support increasingly important industry areas (e.g. for bioengineering).
• There should be an 'Expression of Interest' process for ARC and NH&MRC grants to free up peoples' time (this is a suggested solution to address the productivity issue of lost time for doing the research instead of finding money).
• There is a need for rapid response seed / pilot programs to enable new ideas.
• There is a need for a seed funding scheme for new research directions.
• The nature of existing funding schemes such as the DP grants are not well suited to instrumentation research. Little funding is accessible for the development of the demonstration devices or prototypes of the type needed to engage significant industry or venture capital interest.
• Funding should be outcome based. Funding proposals should be in the public domain to verify achievements against claims.
• Address the lack of a funding scheme for high risk – high reward research.
• There is a need for a mechanism for short term funding with a quick turn-around time for exploratory research.
• Funding decisions should also include future capability building through training of research students as they feed into academia.
• There is a need for transparent mechanisms to propose, assess and fund large international collaborations, such as participation in ITER and LIGO Australia.
• Travel funds (particularly for PhD students) are important in establishing and maintaining international collaborations and are not expensive in the scheme of things. A gap exists with the suspension of the International Science Linkage program.
• There is a need for more opportunities to support international conference travel to expose Australian research.
• Mechanisms to facilitate and fund international collaborations and programs, as physics is international.
• The majority of Australian research involves collaboration with the western world and there needs to be support for a much deeper engagement with an Asian science future, otherwise Australia risks becoming irrelevant in this rapidly growing and evolving community.
• Nanofabrication capabilities will be needed nationally but also will be needed in every university that is involved in these areas of science. Researchers have to be able to access the facilities on a daily basis and students have to be trained on them.
• There is a need for a funding scheme that funds the operation of national facilities (including key personnel) to get the best return from large investments.
• There needs to be a better mechanism for capturing the true value of interdisciplinary projects and promoting them to take advantage of their high value-add potential.
• The physics community has to concentrate to bring complementary fields together, such as quantum and photonics.
• We perform strongly both in physics and biology/medical science. However, as a physics community we need to be more adventurous and outward looking, and actively seek and build these interfaces.
• There are significant lost opportunities due to difficulties engaging with DSTO, CSIRO, ANSTO etc. There need to be better mechanisms to support interactions with these institutions.

Table 60 Specific needs common to all Physics sub-disciplines

HIGH-IMPACT OPPORTUNITIES AND RECOMMENDATIONS

To ensure that the critical success factors of each of the physics community sectors are addressed, a number of high impact opportunities were selected from the SWOT analyses and the physics community requirements survey.

The following opportunities and recommendations were selected to address the systemic needs of the physics community as a whole. The opportunities and recommendations are therefore highly interdependent.

Research

Goals

- Maintain or preferably increase the current high level of research excellence during the next decade.
- Increase future research capability to an internationally competitive level (long term sustainability) by guiding long-term investments in research infrastructure and human resource capabilities so that bigger and increasingly more complex interdisciplinary research questions can be pursued.
- Attract Australia's and the world's best and brightest physicists to Australia by promoting the quality and attractiveness of Australian physics research groups.
- Ensure Australian physics research excellence is at a level that compels the world's top industry companies to select Australian research organisations as preferred partners for developing technology solutions for globally important problems.
- Maintain the quality of Australia's research infrastructure.

Scientific opportunities for research

The diversity of research programs in each of the physics sub-disciplines and the number of highly successful research groups makes it difficult to achieve a consensus on priorities for future research. Furthermore, it is impossible to predict the origins of future high impact research and what new research directions will emerge.

Currently three dominant research themes can be identified that contain promising opportunities for the expansion of the boundaries of knowledge and for scientific progress. Within each of these, many and diverse research opportunities can be pursued, both nationally and in collaboration with leading international research groups. Many of these could also form the basis for long-term collaborative research ventures with emerging nations.

These three dominant themes are:

The new quantum revolution

After 100 years of development, quantum mechanics is undergoing a major resurgence, stimulated by new applications unlocked by 21st century nanotechnology and the potential to cross over into new domains, including biology.

For instance, it seems likely that devices that exploit the spin of atomic particles will join or even replace the established giant magnetoresistive hard disk read-head technology from the 20th century, and also that new applications for entanglement and coherence will emerge. Harnessing the quantum properties of spin, entanglement and coherence for the storage, transmission and manipulation of information in solid state and photonic systems represents a grand challenge for the coming decade. This new field of quantum information involves new approaches to theoretical investigation and experimental implementation that show promise of yielding potentially staggering outcomes.

Quantum mechanics is likely to play a major role in the understanding of biological phenomena, including photosynthesis and sensing. The possibility of exploiting new forms of microscopy that employ decoherence probes to investigate delicate electromagnetic phenomena in cell walls and other biological structures would open up major new avenues of research.

New understanding of mechanisms to control the interaction of light with matter, especially via the manipulation of light in synthetic nanoscale devices, offers promise of exciting applications including the recently developed metamaterials and structures with negative refractive index. Similar promise is shown by the study and application of novel quantum systems including Bose-Einstein condensates and their even more exotic fermionic cousins.

Many of these innovations will be driven by increasingly sophisticated supercomputer modelling bridging the gap between theories governing the behaviour of matter at the atomic scale and the reality of macroscopic physical systems built from billions of interacting atoms. At the same time, the ability to construct devices in which quantum coherence and entanglement can potentially be controlled provides new tests of the limits of our understanding of quantum mechanical models of the real world.

It will be a challenge for physicists based in Australia to continue to be involved in these global endeavours and capture their benefits for the Australian context; one of the goals of this plan is to provide the information and motivation necessary for Australia to address this challenge.

The quest for new physics and symmetries

The remarkable convergence of physicists working at two extreme scales – particle physicists exploring the most fundamental building blocks of nature and cosmologists exploring the large scale structure of the Universe – offers enormous potential for revolutionary developments in our understanding of our place in the Universe in the 21st century.

Driven by likely advances in theory and experiment, and by new astronomical observations, it is widely anticipated the Standard Model of particle physics will need refinement. Data from the Large Hadron Collider (LHC) and the highly anticipated Square Kilometre Array will bring us closer to understanding the origins of mass, the unification of the fundamental forces, and solutions to the persistent and stubborn problems of the nature of dark matter and the accelerating expansion of the Universe.

The significance of some of the most elegant theories suggesting new symmetries and dimensions will become clearer. The properties of matter and energy under extreme conditions will be measured in colliders on Earth and in the remote laboratories of neutron stars as revealed by the observation of gravity waves and new theoretical models.

Just as nobody in the 1920's could have anticipated that the electron and photon and the theoretical construct of quantum mechanics encompassing them would form the basis for multi-trillion dollar industries in electronics, computing and manufacturing, it is impossible to envisage the opportunities that will develop from investigations of sub-atomic particles and the farthest reaches of the Universe, and the theoretical explanations they generate, may lead to.

Mechanisms to provide opportunities for Australia and Australians to continue to be engaged in the major international collaborations and experimental facilities testing these ideas need to be preserved and enhanced.

Physics transforming our lives

There will be rapidly increasing opportunities in the next decade to harness outputs from physics to serve our society. Examples include generating electricity with minimal environmental impact, advanced tools for medical imaging, diagnosis and therapy, and informing government decision-making on issues of long term and global significance.

Just as Faraday and Maxwell ushered in an industrial revolution so profound and all pervasive that it is impossible to imagine everyday life without electricity, so the quest for low carbon sources of power promises a similar revolution. Assessing and addressing the challenge of climate change as the 21st century unfolds will require sound physics and the collaboration of teams with expertise across the innovation continuum, including the discovery of new materials and processes to the applications of those materials in new ways.

While low carbon sources of power are becoming more substantial, they still remain stubbornly minor in proportion to demand. We should anticipate revolutionary physics-based discoveries in the field of energy storage and power conversion and perhaps, if climate change triggers a substantial crisis, the development of radical mitigation strategies. Demands for power efficiency and more accurate climate models will rise. Innovative combinations and blending of what are now distinct technologies could lead to secure network control systems based on quantum cryptography for the highly dispersed power sources typical of renewable energy, as well as new methods for harvesting energy based on subtle tweaks of organic polymers.

In the longer term, generating electricity from controlled thermonuclear sources presents formidable challenges that will require a deep and prolonged effort from global consortia of physicists and engineers. Close collaboration between multidisciplinary teams will be required to meet these challenges.

The eternal quest to improve health and diagnose disease has been a constant driver in the development of new imaging technologies, most of which have their origin in fundamental physics research. The promise of revolutionary lab-on-a-chip technologies is likely to incorporate radical new fabrication technologies exploiting physics at the boundaries with chemistry and engineering. Even more exciting is the potential for the incorporation of artificial devices within the body to enhance degraded functions, perhaps with built-in internal energy harvesting systems to provide the necessary power. The distinguished track record of the bionic ear and the promising new program in bionic vision provide strong foundations for these revolutionary advances.

Research funding

Australian universities have been very successful in receiving competitive grant income from several sources and especially the ARC. However, opportunities exist to expand physics research more substantially through more novel schemes that address the specific needs of Australian physics.

Maintaining and expanding research infrastructure, including super-computing infrastructure, at a level that is effective in supporting the continuous drive for excellence of Australian research organisations is essential in the quest to attract the world's best and brightest young physicists and national and international collaborators.

Opportunities exist to address the important requirement identified by several sectors of the physics community of pursuing larger, more ambitious research questions, that can only be tackled through more courageous and interdisciplinary approaches.

Recommendations

1. **Increase the global competitiveness and impact of the Australian physics research sector**

Options for supporting activities could include:

- Supporting of physics infrastructure by implementing mechanisms to finance upgrades and operational costs of major national research infrastructure, including the provision of qualified support staff.
- Establishment of a Landmark Funding Scheme to support major research initiatives that fall outside the scope of current funding schemes, such as for example the Laser Interferometer Gravitational-wave Observatory, the Square Kilometre Array, and bionic vision.
- Maintaining predictability of funding levels indexed at least at current levels to facilitate the pursuit of important research questions and emerging ideas in all areas of physics.
- Establishment of a Theoretical Physics Institute in Australia to leverage existing but dispersed excellence in this area to enable higher impact and support of research of other physics disciplines.

Internationalisation and cross-disciplinary research

The importance of maintaining existing research relationships with leading research organisations and nations but also of building and expanding research relationships with emerging nations requires that effort must be coordinated and government support is provided to establish these relationships without losing research productivity through diverting effort away from research.

The Australian Academy of Science in a recent position paper to the Australian government[101] clearly outlined the rationale for increased investment in supporting internationalisation efforts. The recommendations included increasing the funding for collaborative innovation projects, for programs supporting early to mid-career researchers, and for building strategic partnerships. Further, the Academy recommended to invest in improved awareness campaigns, improved governance and improved diplomacy for Australia to adapt to future changes to the global scientific landscape.

2. **Make the expansion of international and cross-disciplinary research participation central to Australian physics**

Options for supporting activities could include:

- Introduction and expansion of existing schemes to fund Australian participation in major international physics research consortia.
- Introduction of national schemes that provide access to major international laboratories and facilities and support the participation of Australian physicists in interdisciplinary research groups.

[101] Australian Academy of Science: Australian science in a changing world: innovation requires global engagement.. November 2011

Systems to enable cross-disciplinary research

The future of physics research will lie not only in international collaboration but also in the expansion of inter-disciplinary research; therefore, experiences gained from working in large international and interdisciplinary teams will benefit Australian physicists by facilitating the exploration of increasingly complex research questions at the boundaries of several disciplines.

Recommendations

3. Encourage the participation of physics in interdisciplinary consortia to address problems of national importance

Options for supporting activities could include:

- Develop schemes that support large coordinated multi-disciplinary teams.
- Develop schemes to support ambitious research to address national priority areas with innovative solutions.

Education – Creating a physics-enabled workforce and community

Goals

- Create a more physics-informed workforce and community through better physics education.
- Attract more students into physics at all educational levels.
- Increase the number of appropriately qualified physics teachers in primary and secondary schools to ensure students are given the prerequisite knowledge, opportunity and motivation to study physics both as a major degree and as required subjects in other courses science based courses.
- Reduce the gender differential in physics competency at all school levels.

Opportunities

The greatest opportunities to achieve the overarching goal of a more physics-informed workforce and community are seen through the invigoration of primary and secondary school physics education. Four of the top ten ranked physics community requirements were addressing the needs of the physics community to improve teaching of physics at all school levels. The top requirement overall was for a strong physics curriculum in schools.

Invigoration of primary and secondary school sector physics education, combined with appropriate mathematics education, will lead to positive domino effects in terms of increased competency and motivation of school students to study physics at tertiary level. This in turn is expected to lead to positive effects in terms of higher availability of skilled graduates for the higher education and research sector, industry, business and government.

Students who select other career paths, but are required to take physics classes, will benefit from better physics education at school. This will lead to a more highly skilled workforce in many professions.

A further benefit of improved physics education at the school level will be improved science literacy of the general public as many of the students, who will not study physics at a tertiary level, will have an increased understanding of the potential of physics and physicists to solve important global problems.

The need for substantial focus on teaching physics topics in primary school and the early middle school years is important to reverse the current trend to lower performance of girls in the physics and mathematics.

Recommendations

4. Invigorate primary and secondary school physics education through raising the skill base in physics learning and teaching to best international standards.

Options for supporting activities could include:

- Develop and implement an action plan for improving primary and secondary science, mathematics and physics teacher training so that it is comparable with the best international standards.
- Develop a national school curriculum for physics that celebrates its analytical and quantitative reasoning and encompasses the fundamentals of physics, as well as their applications in today's life.
- Strong engagement of the higher education sector in the development of the national curriculum in physics, mathematics and the sciences.
- Introduce a mandatory requirement that teachers are trained in physics to three years above the level at which they are required to teach physics.
- Endorsement of an undergraduate science degree together with a teaching qualification as the preferred qualification option for Y4-12 physics teachers.
- Implementation of the recommendations of the Grattan Institute report '*Investing in our teachers—Investing in our economy*.
- Support a new specialisation category of "maths and physics" teaching, making the two interchangeable.
- Introduction of options for science, mathematics and physics teachers to allow them to study part-time for a teaching MSc.
- Promotion by the higher education sector of teaching as an attractive career proposition for physics trained graduates.
- Encouragement of physicists from non-academic and research professions to enter the school education sector as teachers and mentors.
- Develop initiatives to address the underlying causes of the under-representation of girls in physics at all levels of school education.
- Reward excellence in physics teaching.

5. Strengthen the quality and skills of Australian physics graduates and PhD graduates, measured against their international peers, by ensuring enhanced physics learning experiences and outcomes in higher education institutions.

Options for supporting activities could include:

- Agreement of Australian higher education providers to ensure that the Australian physics PhD should be comparable in the breadth, depth and duration of training to those in the USA and EU.
- Support research on and implement the findings of leading physics education research.
- Use and share best practice teaching resources and technology between higher education institutions to enhance learning outcomes.
- Provide a balance of learning experiences between theoretical, experimental / observational and computational physics to ensure 'employment readiness' of graduates not only for research but also for industry and business.

6. Raise the national consciousness of physics, its value and its profile in the public eye

Options for supporting activities could include:

- Develop and implement a coordinated campaign by professional societies, higher education institutions and research organisations to raise awareness about physics, how evidence and data are interpreted, and about the role of physics in providing solutions to many of the major technical problems facing our economy and society.
- Commitment of resources by the higher education and the research sectors to supporting high quality outreach programs with long-term impact that can reach and engage all Australians.
- Develop programs and commit resources to promote the value of physics and physics education and careers to school students, parents, industry, universities and government bodies.

Capturing the full human potential

Goals

- Increase the talent pool in physics by attracting and retaining more female talent
- Provide equitable access to all physics career paths
- Increase the number of students choosing physics as a career by promoting the whole spectrum of career paths and their equitable accessability in the physics domain
- Provide school students, undergraduates and graduates with information that allows them to make informed decisions about career choices

Opportunities

Opportunities exist for enabling equitable access to career paths. The endorsement and consistent application of Research Opportunity and Performance Evidence (ROPE) principles in workplaces where promotion is based on research performance is an opportunity to make the intent of enforcing equitable access to research positions transparent. Opportunities exist for developing additional metrics that are not only addressing research excellence but also for example excellence in teaching, commercialisation, or cross-disciplinary, industry and technical expertise to facilitate the cross-organisational transfer of skills and valuable expertise without penalising non-traditional research career paths.

Recommendations

7. Capture the full human potential in physics by providing clear career paths and enforcing equitable access to sustainable careers

Options for supporting activities could include:

- Provide appropriate information for school students, undergraduates and graduates so they can make informed choices about future career pathways, such as for example teaching, research, government or industry employment.
- Consistently enforce ROPE guidelines in assessing candidates for research positions and for internal and grant funding.
- Introduce a voluntary self-reporting mechanism for providing information on equity metrics for research organisation and departments.
- Endorse the recommendations of the Bell report on Women in Science.
- Develop initiatives to address the underlying causes of the under-representation of girls entering the physics degree courses.

Productivity

Goals

- Increase research productivity to a higher level to achieve greater international competitiveness and impact
- Achieve greater organisational agility in adapting to challenges in the research funding environment and to be able to take better advantages of arising opportunities.

Opportunities

Opportunities exist to encourage funding agencies to simplify their funding processes to reduce the administrative burden and cost associated with preparing and assessing physics research proposals.

An expanded set of process and progress metrics, in addition to the current publication-based metrics, to evaluate how achievements track against organisational goals and milestones will be beneficial in allowing research organisations to analyse how they are tracking towards their strategic goals. Having access to a more expanded set of data will enable organisations to, for example, track their progress against funding and equity goals, monitor changes in physics discipline profiles in terms of attracting new talent, and gather information about the effectiveness of their outreach programs.

Recommendations

8. Increase research productivity by reducing administrative overhead and cost associated with managing the funding processes

Options for supporting activities could include:

- Encouraging the simplification of funding schemes that support physics research.
- Provide funding agencies with data that quantify lost research productivity due to inefficient funding agency processes.
- Collaborate with the major funding agencies to improve agility of the funding process to enable responsiveness to international research opportunities

9. Develop additional metrics for evaluating organisational and individual excellence that are not only results focused

Options for supporting activities could include:

- Develop metrics for academic activity which are broader than those based simply on publication output and citation, including measures of interaction with industry, commercialisation and the commercial impact of applied research.
- Develop an expanded set of metrics that can be used for tracking progress and process improvements (such as for example equity related activities, achieving diversity of funding, meeting milestones in developing collaborative programs etc).

Interaction with industry and business

Goals

- Facilitate the development of closer relationships of research organisations, and especially universities, with industry and business.
- Facilitate the development of close research relationships with key national and international companies to access industrial research teams for collaboration and to diversify funding sources for research.

Opportunities

Improved relationships with industry will allow the Australian research sector to develop and expand additional research collaborative arrangements, nationally and internationally in research areas that are compatible with the directions of Australian physics research.

A strategic approach to achieve more productive industry will require closer collaboration with research organisations nationally and internationally. It also requires that interactions and scientific collaboration with cross-disciplinary teams such as engineering, and the more applied physics sub-disciplines be strengthened.

Opportunities exist for capturing the expertise of researchers in both the research sector and industry if better on- and off-ramps in and out of research organisations and industry can be created without penalising career paths due to interruptions.

Opportunities exist also to provide industry with more visibility of research achievements from the research sector as it is very difficult for industry and business to identify and evaluate the usefulness of research that is conducted in Australian research organisations.

Strengthened relationships with industry will also highlight employment opportunities for graduates in industry and allow industry to identify talent and access capable graduates for employment.

Recommendations

10. Develop stronger relationships between the higher education and research sector with industry and business

Options for supporting activities could include:

- Develop models for constructive and lasting relationships between industry, business and the higher education sector.
- Develop models for facilitating cross-sector collaboration between higher education institutions, government research agencies and industry and business.
- Develop mechanisms and metrics that facilitate entrepreneurialism and commercialisation of researchers within research organisations without penalising career prospects.
- Establish a national forum to facilitate the seeding of new technologies and interaction between universities and industry
- Convene, under the leadership of government, a summit or workshop with the aim of developing an understanding of mutual expectations of government, industry and academia, and to develop more effective modes of interaction and collaboration.

CONCLUSIONS

The laws of physics and their applications shape the fabric of society; the way we communicate, travel, receive health care, in short, the way we live our lives. Australian physicists have played a substantial role in contributing to this knowledge and application of these principles. This decadal plan seeks to understand how these valuable contributions can continue to underpin Australia's future. To achieve this aim in the context of a strategic plan, the current position and the external conditions need to be clearly identified so that future opportunities can emerge, and a roadmap devised to ensure that the physics community reach the specifically expressed goals established from the stakeholder groups.

The physics community is defined as a number of stakeholder groups. These are: secondary schools, higher education, researchers, industry and business, the government and domestic and international communities. Each of these stakeholder groups have been evaluated in detail.

Secondary school students ranked poorly in attitude to and performance in the study of physics. A substantial opportunity exists to improve the grass roots of physics education by improving the support to teachers to ensure improved quality of physics education in schools. Capitalising on this opportunity will have a very high likelihood of positively impacting all of the other stakeholder groups, as well as ensuring excellent physics outcomes for future generations. Baseline data and metrics exist to quantify the results of efforts to improve this sector. Particular attention should be paid to indigenous and gender inequalities.

Despite the shortcomings of secondary school physics education, undergraduate training is well subscribed and excellent faculty and programs continue to attract international as well as domestic students. This success provides further support for the strategies outlined to improve secondary school physics education.

The research community is a beacon of success in Australian research; although, true measurement of outputs from the physics community is likely understated due to the inter-relationship of physics with other disciplines. The ARC Centre of Excellence program has been well suited to support physics research and pursuing similar funding schemes is a high priority to maintain the research sector's high level of performance.

Industry and business are vital parts of the overall physics community and there are numerous latent opportunities that may be realised by greater interaction between this sector and academic researchers. The anticipated gains are expected to be shared mutually and include greater commercialisation success and superior innovation through the intermingling of pure and applied research endeavours.

The government and community sectors are daily users of the outputs from the physics community. In our market force economy, these actors play an important part in defining demand. The discipline stands to gain from appropriate promotion of physics to these stakeholders and in particular encouraging the public to engage with how physics shapes our daily lives and its potential for future developments.

The roadmap outlined in this decadal plan comprises specific recommendations for:

- Building on Australian physics research excellence through investment, funding and structural vehicles as well as engendering international and cross-discipline research.
- Invigorating physics education in schools and universities.
- Capitalising on unfulfilled human potential by attending to gender and indigenous inequalities.
- Improving research productivity; and
- Generating productive interactions between academia and industry.

The interconnectedness of the various sectors of the physics community increases the complexity of implementing the recommendations in this plan; however, this also provides significant opportunity to embrace engagement between the different sectors and thereby foster an harmonious physics community.

Australia has long been the beneficiary of the industry and innovation from the Australian physics community. This decadal plan strives to secure this role of physics in underpinning Australia’s future.

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AUSTRALIAN INSTITUTE OF PHYSICS

PHYSICS DECADAL PLAN 2011

Australian Academy of Science

APPENDICES

Appendix 1 Decadal Plan development timetable

Revised Indicative Timetable	Key Tasks
September 2010	▪ Informal meetings with key Physics stakeholders to shape up process
October 2010	▪ Appointment of Working Group Convener ▪ Appointment of Working Group Committee (WGC) ▪ Meeting of Convener with stakeholders in Canberra to discuss terms of reference (facilitated by FASTS) ▪ Development of terms of reference of working group ▪ Allocation of portfolio of sub-disciplines to WGC members ▪ Revisit sub-disciplines and consolidate ▪ Invite and appoint Sub-discipline Report Coordinators (SRCs) ▪ Development and circulation of instructions to SRCs ▪ Announce process in "Australian Physics" and other channels of communication ▪ Appointment of research officer (consultant)
October-November 2010	▪ Working Group Activities
December 2010	▪ Preliminary reports due back from SRCs ▪ Town Hall meetings of sub-disciplines to be held on the Friday of Australian Institute of Physics Congress (AIPC) week (December 10) ▪ Presentation to Heads of Physics meeting at AIPC ▪ Formalise membership of the National Committee for Physics (NCP) 2011
January-March 2011	▪ Each Working Group produces report based on their sub-field.
April 2011	▪ Meeting of WGC to consolidate reports and revisit process ▪
May 2011	▪ Progress report submitted to NCP: May 26 ▪ Progress report finalised for circulation and request for comments ▪
June 2011	▪ Circulation of first draft of the strategic document amongst Physics stakeholders ▪ Roadmapping workshop ▪ Feedback period for progress report
July 2011 August 2011	▪ Meeting of WGC to consider feedback and integrate into report ▪ Circulation of final draft of the strategic document to the community and request for feedback
September 2011	▪ Printing, publication, etc. ▪ Publication and Launch (pending Ministerial availability for public presentation) ▪ End of project report & financial statement

Appendix 2 Terms of reference for the Decadal Plan working group for the National Strategic Review of Physics 2011

Statement of task

- The principal aim of the Physics Decadal Plan is to assess the current status of the activities in the fields of physics (except astronomy) and to prepare a strategic plan that will be addressed to the Australian Academy of Science, agencies that provide support for the field of physics such as the Federal and State Governments and their agencies, the scientific community, industry, and the public.
- The Decadal Plan Working Group and its sub-discipline working groups will conduct a survey of the field of physics and identify strengths, weaknesses, gaps and opportunities for increasing national capabilities in physics research, education and commercialisation of research results.
- The Decadal Plan Working Group and the sub-discipline working groups will recommend strategies for the most important scientific, technical and supporting activities for the next decade from 2011 to ensure that physics research and education capabilities are maintained at a globally competitive level for the next 30 years.

Scope of the strategic review and decadal plan

The review will cover:

- Science and research across all sub-disciplines of physics over the complete spectrum from fundamental and theoretical research through to applied research and R&D in industry.
- Research infrastructure for conducting world class physics research.
- Human resources and their skills, quality, equality and career path options including related infrastructure and program requirements.
- Educational programs within the school and academic sectors as well as in related disciplines and industry.
- Relevant activities in other countries that may lead to opportunities for collaborations and other forms of international cooperation in the fields of physics.

The decadal plan will develop a strategic framework for physics in Australia over the next ten years (with and outlook on capability needs over the next 30 years) which will

- Ensure vibrant, competitive and sustainable physics research of global impact that covers the whole spectrum of the innovation continuum from fundamental research to viable and practical applications.
- Stimulate mutually beneficial interactions among academia, business, industry, government, research institutions and other users of physics sciences, and
- Ensure a supply of appropriately trained graduates and researchers in physics to fulfil the needs of business, industry, government, research institutions, universities, and other organisations.
- Ensure the physics literacy in schools is increased through appropriately trained teachers.
- Support national innovation and research and development priority areas.
- Make recommendations to allow agencies that support the discipline of physics to make informed investment decisions about funding and infrastructure support.

Appendix 3 Terms of reference for the Physics Decadal Plan sub-discipline working groups and their consultation and interview process

The conveners of each sub-discipline working group are asked to take responsibility to consult with relevant people in the sub-disciplines of their cluster. Please identify strengths, weaknesses, gaps and opportunities for increasing national capabilities in research, higher education and technology transfer. Our purpose is to ensure Australian physics capabilities are maintained at a globally competitive level for the next decade and beyond.

We recommend a semi-structured interview process be used, based on the following questions (please edit these appropriately for your cluster):

1. What is going on in your sub-discipline in terms of research (across the university sector, CSIRO, ANSTO, DSTO and relevant industry) that demonstrates current globally competitive strengths which can form the basis for future capability building (in research, teaching and engagement with the community)?
2. What trends can you see in your sub-discipline that will have an impact on what research will need to be done in your sub-discipline in the next decade?
3. What opportunities do you see for your sub-discipline that can contribute to solving currently important problems (for example: energy, climate change, health, security, Higgs Boson, new states of matter, dark energy, biophysics etc.).
4. What is limiting your sub-discipline to take advantage of these opportunities, what impinges on the quantity and quality of research and what a threat to the global competitiveness of the sub-discipline in Australia?
5. What is needed to overcome these threats and limitations and enhance capability?

Please Note:

The questions above will also be posted on the Physics Decadal Website so interested people can submit further inputs if they wish.

The most difficult task for the interviewers will be to phrase the questions neutrally and to strike a balance between just listening and guiding the interviewee to commit to statements that relate to the questions.

To prevent just 'whinging' and 'wish lists' we encourage you to follow up those types of answers by asking "What will the effect of that be?" This will force the interviewee to stick to specifics rather than generalities.

Avoid leading questions (e.g. "do you think…") or questions that can only be answered by yes or no ("Do you need more infrastructure?" or "Is there as shortage of…"). These questions always need a second follow-up question and therefore waste valuable time. Ask questions that start with 'what', 'where', 'how', 'when' but avoid 'why' as some people feel judged and threatened by it.

Appendix 4 Decadal Plan working group members

Members of decadal plan working group

Professor Hans Bachor, Australian National University

Professor Ken Baldwin, Australian National University

Dr Cathy Foley, CSIRO

Associate Professor Brian James, University of Sydney and Australian Institute of Physics President, ex-officio

Professor David Jamieson, University of Melbourne (Chair)

Professor Ian McArthur, University of Western Australia

Professor John O'Connor, University of Newcastle

Professor Halina Rubinsztein-Dunlop, University of Queensland

Members of the sub-discipline working groups

Cluster Earth (Chair: David Jamieson; Michelle Simmons; Chennupati Jagadish)

Condensed matter and materials physics
Energy and power technologies
Chemical physics
Education

Cluster Wind (Chair: Ian McArthur; Geoff Taylor; Nanda Dasgupta)

Astronomical and cosmological physics
Particle physics
Nuclear physics
Plasma physics
Theoretical physics
Mathematical physics

Cluster Fire (Chair: Halina Rubinsztein-Dunlop; Hans Bachor; Tanya Munro)

Optics and photonics
Quantum information
Quantum computation
Atomic physics
Biophysics

Cluster Water (Chair: Cathy Foley; John O'Connor; Peter Veitch)

Medical physics
Climate and atmospheric physics
Acoustical physics
Hypersonics and fluid mechanics
Industrial physics
Space physics
Geophysics

Cluster Aether (Chair: John OÇonnor, Phil Dooley)

Secondary
Tertiary
Primary
Outreach & Communications

Appendix 5 Decadal Plan town hall meeting process and summary of contributions

Town hall meeting process

Each cluster chair explained the decadal plan and town hall meeting process:

Phase 1 - Physics survey

Phase 1 is an inward looking process to identify where we have come from and where we are at and an outward looking process that defines where we want to be. The town hall meetings today are a very important part of the survey and getting the views of the physics community. We want to know your current thoughts on the current state of physics. What are the national and international trends, the important opportunities and risks, and we will be asking you for a white paper submission via the decadal plan website (http://www.physicsdecadalplan.org.au).

Phase 2 – Evaluation and prioritisation of ideas and opportunities

Phase 2 will be an evaluation of the white papers and the ideas that will be put forward today and in targeted interviews that further explore the issues identified here and in the white papers, and also to identify what the opportunities are to assess collaboration, funding and infrastructure. Today is not about funding.

Phase 3 – Strategic plan development

Phase 3 (April/May 2011) will be the strategic plan development. We will conduct a series of workshops to develop a roadmap and a communications strategy and where we will place the plan and how we communicate it. We will make a formal submission at a gala event in Canberra in July 2011 where we will formally present the plan to the Academy of Science, to whom we are charged reporting this, and to the Australian Research Council.

The physics community and sub-disciplines have been loosely grouped into four clusters. It is recognised that there is overlap between clusters and that some of the sub-disciplines may have not been mentioned in detail. The aim of the subdivision into clusters was to allow, within the allotted time of one hour, as many members of the physics community as possible to provide input and so quadruple the opportunities to speak.

The audience in each meeting is asked to provide up to 90 seconds of input into three questions.

Question 1 (10 minutes):

What were the most important breakthroughs in the field of physics in the past decade? Who did that work, what was their motivation, what where the long-term implications of these breakthroughs, and what resources did they use to achieve these breakthroughs?

Question 2 (30 minutes)

What are the most important questions and opportunities for the next decade and beyond? What will be the spin-offs, what are the social/industrial implications in both the Australian and global context? What resources will be needed?

Question 3 (10 minutes)

What is the risk if the if the questions are not answered, in the short and in the long term? What are the barriers (ignoring funding) for physics in Australia for capturing the opportunities in physics?

Summary of Contributions

Contributions from AIP Congress delegates identified a number scientific breakthroughs that have a large impact on society, economy and science, and a number of issues, opportunities and risks. As the same issues, opportunities and risks were identified in more than one, and often all of the clusters, this summary of contributions is therefore presented according to the common topics rather than according to cluster. The comments of individual delegates are cited verbatim below in italic font, as transcribed from the audio recordings. Each paragraph provides one comment of one delegate. Even though several delegates may have phrased their concern or issue similarly in a parallel cluster the most succinct comment on a topic was selected to best illustrate the issue.

Question 1 - What were the most important breakthroughs in the field of physics in the past decade?

Nobel Prize on graphene:

> *Andre Geim and Konstantin Novoselov from Manchester University did it, the motivation was interesting, because everyone said 2D matter could not be done and they set out to do it and the long term implications are likely to be something that we do not see very often and that is the availability of resources through our technology, typically today throughout all the flat panel displays there is a need to transfer electrons. Resources used were basic facilities and advanced instrumentation, things that we also have in Australia but also time. They were given time to do exploratory research. What was special about the researchers in Russia, the Netherlands and finally Manchester and why was this not discovered in Australia? They were both a little bit out-of-the-box researchers. I doubt whether they would have gotten an ARC grant for something everyone was saying could not be done under conventional wisdom. They just were prepared to have a go and their university supported them.*

New semiconductor materials:

> *Lots of work by people in Japan and US and Europe. Motivation is to research superconductivity and applications of this work in industry and in general. Resources for this type of work are important as these types of materials are incredibly complex, very difficult to synthesise & make. Often their properties are such that different techniques yield different results and sometimes that difference is very important.*
>
> *High temperature superconductivity. A system called Landtem which has been commercialised and which is used around the world and it found billions of dollars of mineral deposits and has been*

> *identified internationally as one of two commercial outcomes from high temperature superconductivity.*

Science of quantum systems:

> *One of the most important advances is the ability to build quantum systems from the ground up, with particular desirable properties. In Australia there have been some very important breakthroughs to engineer quantum systems with the kind of properties we want rather than going out and finding stuff and studying its properties.*
>
> *One of the breakthroughs is the development of scalable quantum computing technologies. Australia has been a world leader in one of the 3 scalable quantum computing technologies, in optical quantum computing. The motivation is to solve problems that cannot be solved on classic computers. The implications are many.*

The control of light at the nanoscale:

> *One of the main breakthroughs in the past decade is metamaterials or the control of light at the nanoscale. We are in a transition period and it is still happening now. Who did that work? Probably overseas work, here in Australia probably ANU, a little bit at CSIRO. What was their motivation? I suspect it was purely exiting physics. It was really the concept of controlling light at the nanoscale. The concept of metamaterials is very interesting because you are creating artificial atoms or artificial structures that have specially designed properties that you design in. When you build this structure up you then created an artificial material. What are the long term implications? It is the control of light and of radio waves. Metamaterials have been designed for example for antennas in mobile phones.. What are the resources they used? In radiofrequency it is very simple stuff, radio, circuit boards type technology, in the optical regions it is lithography.*

Interaction of light with matter and at the biological cell level:

> *An enormous variety of work that has been done on Lasers in Australia and outside Australia. It has enabled physicists and practitioners to get to the bottom of resolving difficult questions that were previously impossible to even think of, like healing with light. Healing with light is possible and this is because of the development of lasers and their characteristics. And also the synchrotron we are having in Melbourne helps us with in-depth understanding of viruses and to develop pharmaceuticals to do specific jobs etc. So I would emphasise the aspect of the interaction of light with matter at the cell level.*

Climate science and modelling:

> *The recognition of the importance of the ozone hole to climate change. That is something that only happened in the last 10 years and the fact that it is masking the Antarctic warming over the Antarctic continent where the peninsula is warming at an incredibly high rate. And so when the ozone hole is repaired we will have a rapid change in the Antarctic ozone, in the Antarctic warming that will lead to increased melting and to increased sea levels. That will be a global effect.*
>
> *There seems to be an emerging recognition by companies of the importance of climates. Particularly energy companies that look at wind power.*

The bionic ear:

> *The Bionic ear was one of the most significant contributions of the last 30 years, in which physics played a very large role. It solved the problems of thousands and thousands of people.*

High pressure thermal plasmas:

> *In the last 10 to 15 years there have been a number of processes developed to use these plasmas to destroy ozone depleting substances, for destroying halocarbons, fluorocarbons, and more recently turning biomass and garbage into specific gases and ultimately into ethanol. There is a fair chance that in the next 5 to 10 years our cars could be powered by ethanol produced from biomass that produces a lower carbon footprint. Plasmas are one of the processes for that.*

Wireless communication:

> *One of the classical things is wireless that although it is older than 10 years, has been picked up and developed since then. It was something that was spun out of radioastronomy at CSIRO.*

Space weather and its potential influence on the lower atmosphere and global systems:

> *We only recently have the predictions of the importance of space weather on the economy and society to quantify. A study by the American Academy of Science in the last two years which predicts that if one of the great solar driven geomagnetic storms of 1921 had occurred today, it would take out over one third of the American power grid without being able to replace those transformers within an excess of a couple of years, with a trillion of dollars in damage in the first year and over 10 trillion in the first 10 years.*
>
> *In my particular field, one thing that is very important is an increase in realisation that space weather might actually affect the lower atmosphere. This has bearing on atmospheric physics but this movement has a long way to go yet because this is not yet fully accepted.*

Theoretical physics, modelling and simulation:

> *One of the important things has been the incorporation of computers into physics and now it is a problem doing physics without having some kind of simulation. Also the interest in engineering materials and to simulate biological parts that are compatible is a new research area, simulate biological processes and create biological materials.*
>
> *I'd like to suggest that research at the interface of biological systems has been significantly improved over the last ten years and that has been done by people overseas and some in Australia too. The motivation is in the applications such as diagnostics and generally understanding biological systems better. The implications are immense and relate to human health and management.*
>
> *Currently Australia is reasonably well served for condensed matter theory but we need to maintain that.*
>
> *When we are looking around the scientific community and theoretical physics, we don't have a lot of what we would call mainstream theoretical physicists. One line of work in that area has been very successful and that is condensed matter physics where people are looking at strongly correlated systems, mechanical systems. What is happening there in this area of research that there is increasingly a strong overlap between condensed matter physics, optical and quantum information.*

Education:

> *The most important breakthrough in physics education in the last 10 to 15 years is the prominence given to education [models] in the universities by Carl Wieman, the 2001 Physics Nobel laureate. His motivation was to give back to society. There has been a movement in physics education – he saw a need for it for scientific literacy but also for science in general. There is a whole movement forward in Europe how physics is taught in the departments of science. This is also being looked at in the US, e.g.*

in Maryland and Colorado. The long term implication of that is that if Australia doesn't get on that bandwagon now we will lose out in a big way, in our knowledge, our economy, innovation, and we will never get that chance back again. Resources they used? Basically Carl Wieman received $10M to do what he is doing, but the largest resource is coming from physics research groups.

Commercialisation and Industrialisation:

If you look at the industrial activity in physics in Australia, 20 or 30 years ago there were a number of large industrial laboratories, BHP Australia was an example, and I can think of a couple of others. Those virtually all have closed down but in that time we have quite a number of small high tech companies that have come out of physics departments.

Question 2 - What are the most important questions and opportunities for the next decade and beyond?

Quantum systems:

What we need to do is to understand how to do very large scale quantum systems. Quantum mechanics is now very well understood, we need to understand how we apply these to thermodynamic and new particle systems. The spinoffs are how to understand chemistry on the fundamental level to what is going on in real life systems and so that we can design drugs and things that we haven't even dreamed of.

Nanoscale materials and the control of light at the nanoscale:

There is a huge technological potential spinoff, solar collectors and conversion, using light for the conversion of chemicals.

Silicon photonic, nanoscience and photonics, that is changing the paradigms of photonics of the 21st century and it going to lead to new industry applications. Really, that will lead to opportunities.

The temporal frontier:

The temporal frontier is very important; attosecond science and beyond is an area of future science.

Computation and modelling:

I can see the demand increasing on computational power in biochemistry, biophysics.

Climate change:

Climate change will run over the top of everything. We need to look at new alternative energy supplies and all the other problems arising from that.

We need to demonstrate physics is valuable for solving the questions of climate change and power. At the moment we are seen as part of the problem and not the solution. If we are talking about nuclear power people become suspicious of it. So we need to establish programs in the next decade to demonstrate the value of physics by putting resources into energy and power.

Australia is probably more than any other country exposed to global warming because of the effects of climate change and we are running out of carbon based fossil fuels and we rely to a large degree on coal mining. That will be a no-no in 20 years' time. So we need to train the people to a) address the question of climate change and b) the question of renewable energy or whatever is going to power Australia in the future. We need to train these people now and create opportunities for them.

Collaboration:

One of the things that will be important in the future will be networking between scientists in different disciplines. Because a lot of the problems we are facing, both in pure science and in applied science , cannot be solved in one sub-area alone. It needs structures to support that networking.

Looking at the physics-bioscience interface, there are many, many examples. My concern is that the funding mechanisms are not there to encourage or aid or enable people to work together. Even in CSRIO we are not good working across fields.

In the funding agencies, the biomedical and the physical science submissions are assessed by two different groups and things that fall in between often get ranked very lowly by both groups, really good projects that just don't fit in.

To me when I was a student I was told that the future of physics is in the confluence of the disciplines. This is an area that we are not handling very well. When you go to the ARC committees you see people pushing their individual research areas. But I think if you want top entrepreneurial opportunities we need to look at the interdisciplinary areas and handle it in a much more coherent manner.

One of the areas of interaction is the interaction of quantum physics with biology.

At the level of large scale international collaborations I don't think we have a good structure in Australia for assessing those schemes; we want there to be a structure for those to be assessed in a proper peer reviewed way.

There is no mechanism for a national institution for theoretical physics or any such thing like the Max Planck Institute for complex systems in Germany, simply a place where people come to collaborate.

Higher education:

One of the big social consequences of our current graduate programs is that there is incompetence in graduates coming out of Australia.

The competence of Australian graduate students when they finish their PhDs, in the international context, is limited. They do in the Australian context get a competent education but their understanding of physics is limited compared to the people in Europe and the US. The reputation of Australian graduate students is hindered by the fact that they are not offered sufficiently good graduate teaching.

I want to talk about my postgraduate education. There is a limited time we have at our desks for course work compared to overseas universities. That is a large issue.

We can't cover all expertise at honours level where you need someone who is really an expert in the field.

As of two years ago, word wide 67% of physics was condensed matter physics. Condensed matter physics is dramatically under-represented in Physics in Australia. This will have a dramatic effect on our ability to train the next generation of physicists.

The great shift that is occurring is a shift from formal physics education to informal physics education. There is a prediction that the lecture will disappear. We are already preparing for this and our young graduate students in their own time are already putting their skills and their knowledge to developing interactive tools for the marketplace to teach physics better. We need to put bright young graduates and resources into' informal' physics education and make sure it is top quality.

There is not enough time to do the course and there are not enough resources in the departments to do the course work.

Sometimes we go through large theoretical load and the experimental load is very small. We fight to get the resources for experimental science up.

School Education:

We need to concentrate not only on university education but on school education. It is an absolute disgrace that children are going through to year 11 and even 12 who do not have specialist physics teachers and that in this era where we finally understand the most important aspects of science like quantum mechanics, relativity and evolution that we are not talking to young children and we are not using this to communicate to young people and inspire them. We are going to dry up the resource of talented people.

One of the most important things is the National Curriculum. Currently it is a disgrace on the table because it has no understanding of what a curriculum means. It does not have contextualisation.

We have failed to engage our young people properly, despite all the talk about engagement. Kids don't see relevance of a lot of what they do in school but they have become quite acquiescent about it. We just have to switch this inquisitive button back on again.

I used to be a high school teacher many years ago. What concerns me is the devaluation of the so-called eclectic subjects at school, the devaluing of difficult maths and physics and chemistry. So I think we have to try and redress that.

There is an increasing trend in Queensland towards elimination of content from physics courses in favour of topics such as communication skills. I think this is why our graduate students are playing catch-up when they are doing a PhD and beyond.

Something that is clearly coming out of the discussion here is a need for a very strong outreach program that is part of the national curriculum. At the moment the student numbers are just going through the floor. I am not sure if you are aware, in South Australia the numbers in physics and second maths are just going through the floor. This is a train wreck coming.

What is physics?

They do not hear the name physics until they are in year 11. Parents do not understand what physics is.

It is actually the science of everything, the natural world. We need to emphasise that. Chemistry is arguably electron volt physics, biology is …, physics is universal and enabling.

I must say I am a bit pessimistic that in 10 years' time we will exist as a physicist. Because if someone does physics and then goes into meteorology he becomes a meteorologist. The name physicist is disappearing unless we are merging with some other discipline. If we get students and they take physics we couldn't overcome that barrier of "what are physicists supposed to do?". They have to change the name and become materials specialists or something like that.

I deal with secondary students a bit, and they seem to be confused about what physicists do and what engineers do and they believe engineers actually do the stuff that scientists do. They have this idea that engineers do all the technological stuff - but what do scientists do? We don't know.

Physics literacy:

One thing I want to say is about scientific literacy and the big horrifying setback that we have seen in the last few years from our cultural context in how tragically wrong the climate change debate has gone. When we suddenly realised that people don't believe evidence, people don't believe scientists anymore. They don't trust us. That whole architecture of trust and where it comes from, we need to look and understand that, where that comes from. We as scientists have failed abysmally. That is really vital not only for the planet to survive but also for building the status of science in society and making that a theme.

I am concerned with the increasing superstition in this world. I am inclined to feel a bit Richard Dawkins-ish.

You got to be able to participate in science discussions internationally. You will never be invited to the inner club if you can't understand and participate.

Getting a broader understanding of how science comes about and that it is not something that, if enough people vote on it, is true.

We need people with expertise and capability to contribute to the rest of the world.

Communication between physicist and the public:

The way scientists communicate and come to a decision is fundamentally different from the way the public expect a decision being presented to them. The way the media and the mass media work and the way politicians are briefed and come to a decision is fundamentally different from the scientific debate that is necessarily long winded, sceptical, very well thought out. But not always being able to be summed up in a two minute summary for the media. That is what we need to be able to do.

What hurts us is often the media. We try and put our stuff in the media and then you get some crap story which goes viral and which does so much damage. Then trying to address that does not help.

Value and benefit of physics and the image of physics:

There is an opportunity for the next decade to make physics valuable in the eyes of the community, not just interesting.

We should commission an analysis on what the benefits of fundamental research has been. Our British colleagues found that an extremely useful thing. You cut one dollar out of research funding and you cut ten more out of the economy.

A career and the image of physics:

There won't be enough teachers and certainly not enough qualified teachers.

I am hopefully going to be a high school teacher next year. I have a real fear that in ten, twenty years there will be no one there. I have this problem in my head that I enjoy physics teaching and there is no other motivation to do physics teaching other than being really, really passionate about it, and that can't be it. I have a real fear that there is no other incentive, of money, of how people see you, for people to go into that career. And I fear that if you don't address that, in twenty years you will not have any physics teachers coming through to do a PhD. Because without having physics trained teachers, studying science will be really hard.

For the younger generation money means a lot. If for example you are doing maths, there are so many other things you can do to make money.

You can all be passionate and drive yourself into the ground for very little return and very little prestige and social recognition. There needs to be some sort of a revolution of funding to change that from the ground up.

The problem of attracting good physics students into teaching lies with most of the academics in teaching. When we see our good quality third year students coming through we straight away encourage them to go into a research program and PhDs. We are pushing the best students into a research career path. This is a good outcome but we are NOT telling students to go into teaching enough.

What I see in kids coming into first year university or the lack of kids coming into physics or doing the harder sciences, they seem to think in the so-called 'high school' that it is better to do something else. Whether it is better because they think they will have more money or they think they will have a better life, better because it is more socially responsible. They are not too clued on this.

You need to have educated people who can have careers in government and industry, in education.

I would like to add that physicists in Australia have a very stable life and young people do not look up to them. My son does not look up to me and none of the children I dealt with see me as a successful person and I have visited many, many schools and I think engineers is the way to go.

I went into as a chemical engineer because I was told by various people that I would definitely get a job. I think many people say to themselves engineers definitely get a job. Whereas I think that is not true for a scientist.

You definitely see jobs for engineers but you don't see jobs for physicists very often.

The risk is the name of physics and the perception of physics. The point I want to make is about outreach. A lot of what we have said is really about outreach, about getting the message to the general community and the young people about what physics is and why it is important. And at the end of a degree in physics that you are employable in a multitude of things and that the world is your oyster.

Links with Engineering:

We should emphasise the connections with engineering when we are developing our plan. These plans can become very insular and for us what makes a lot of physics practical is engineers. We should emphasise that.

One of the big problems we have in getting students into science and physics in particular is that engineering is such a strong profession. If you are not an engineer you can't do anything that an engineer does. For many types of engineers that is just nonsense, yet it is such a strong profession. You are just excluded automatically. That is not the case in other countries.

What is missing is entrepreneurship. There is a disconnect between the science and engineering world trying to take some of that good science and create a high tech industry in Australia. It would be great to see a vision that revolves and says: in the next decade not only will we do good science but we are also going to try and create an industry in Australia, a real high tech industry that comes from our science.

Commercialisation and industrialisation:

…. number of people we have spoken to have said 'what you are doing is really good, how can we get that seamlessly into electronics?' Somehow a lot of the optics work that we do, if we can start to bring it together with electronics, seamless electronics, then we basically have a route to commercialisation. Maybe that would be something the plan could address.

So attempting to build national resources in sensing detection processing and such industrial applications could result in spinoff companies and also very closely tied to that economic benefit to Australia.

To get the entrepreneurship we got to get the people interested in doing it. I have been involved a couple of times and I would not go near it with a barge pole, and I would not recommend anyone I know to get near it with a barge pole. I would say 'Publish it on line and let someone overseas commercialise it' . Do not go near the Australian commercialisation office. This is a real problem.

Question 3 - What is the risk if the if the questions are not answered, in the short and in the long term?

Interdisciplinary research and collaboration:

I think one of the greatest risks we have is by looking too much inwards into physics and not seeing the opportunities we are having in all other disciplines of science. Take that physics out and cross all those boundaries. Writing that plan we should look how we could make partnerships and grow activities between all the areas of science and empower them instead of just looking inwards.

One of the barriers that I see to that [interdisciplinary] work is the way the ARC is handling the granting structure at the moment. I can see that multidisciplinary physics is not served that well that is one of the things we would want to address.

For a relatively modest investment in international collaboration, CERN is the most obvious, you can add ITER and others, our scientists could have access to it because we would never be able to afford these types of facilities in Australia in the near future. At the moment we have no guarantee we have access and we are in danger of going backwards here in this.

Imbalance in research direction:

The really big things are obvious questions in physics, we are not addressing those. We are swinging more towards technology applications driven applied physics type questions. There are some really big quantum questions that you could be addressing, this is in our area of physics. If you only talk about technology there is a risk.

Higher education:

An obvious risk is, if we don't do anything about the PhD programs, in ten years, our graduates will not be competitive. Particularly in the fundamental sciences we are now getting a lot of push back. For example a typical comment: 'you sent me so-and-so as a postdoc. He is great, despite the fact that he had an Australian PhD education'. They seem to be good in a narrow area but they are lacking the breadth. This is a function of a 3.5 year program. We really need to push back on that. Because otherwise in 10 years we will be seen as a good source of technologists but not of physicists.

It is as simple as this. Australia will cease to be a developed country with a substantial industrial and academic base without enough people who are well enough educated to participate in the international marketplace and societies.

I think you hear it occasionally that higher education is actually a significant export industry for this country and it is a greasy slope. As soon as that starts to slide the international students recognise it and they don't come. You just killed a very lucrative export industry.

That will be an increasing problem. Our current markets are India and China and those countries are developing their education systems as fast as possible and many of their best universities are equivalent to our best universities. Do they need to come here anymore and do they need to attend in ten years' time?

There is another thing I would like to raise and that is our place in Asia. I went to Shanghai to an Asia Pacific Conference and I was the only Australian there, only one of few Caucasian people there and I was very embarrassed by that. We just don't engage in the Asia Pacific area and they are looking for us to engage more and I think there is a real need in the next ten years for us to engage. We tend to interact and go to European conferences. Maybe it is because we have limited travel dollars but I think there is a real recognition for our place in Asia.

One of the barriers is the decline of volunteerism in Australia which science needs to rely on, for organisations such as the AIP, or to do peer review, to do government reports on important issues. It is not only physics that will fall apart, it will be science, the whole system that will go. To some extent this is due to lack of funding but it is also down to the younger generation's attitude. And that is a significant barrier.

School education and physics literacy:

The risk is the image of physics in secondary schools. Barriers is the perceived image of physicists.

It is the perception of physicists in the general community.

One of the barriers is the sufficient supply of appropriately trained secondary teachers. It is really a barrier to the future if we don't get that right.

We have wonderful tools such as the synchrotron and the reactor, wonderful tools for physicists and we would not have enough people from Australia to populate them and that would be really a shame.

Lack of understanding of politicians and media in general and their scientific knowledge compared to crank knowledge or popular knowledge of popular appeal.

Physics science quality metrics and career issues:

It is just falling apart. There is just so much of a difference in what your publication list looks like if you work in a big collaboration or if you work on instrument science, if you don't have a big collaboration or if you are just working with a few guys in a lab – you can't have just a simple system, there got to be a system to inject decisions on quality, not just on quantity.

The type of publications now, there are some very large collaborations, LHC, Atlas, CMS etc with 500 author papers. So the way publications are used as a metric and the way they are liked to be used with h-factors and whatnot, this is complete nonsense.

I think the lack of females in physics, for both men and women we need to get more women into physics. That would be healthier for the discipline. This is one of the last male dominated disciplines.

Appendix 6 List of individuals and organisations consulted

1. Theo Aravanis, Chief Geophysicist, Rio Tinto
2. Brad Atkins, BSc (Genetics), Global Advanced Design Technology Project Manager, General Motors,
3. David Atkins, BSc (Physics), PhD (Physics), Policy Advisor, Strategy & Delivery Division, Department of Prime Minister and Cabinet
4. Prof Clive Baldock, BSc (Physics), PhD (Physics), Head of School of Physics, The University of Sydney
5. Subho Banerjee, BSc (Physics), PhD (Physics), MSc (Economic and social history, Oxford), MSc Environmental Change and Management, Oxford), Executive Director – Strategy & Delivery Division, Department of Prime Minister and Cabinet.
6. Rachel Barker, BSc (Physics), PhD (Physics), Time Series Analyst, Australian Bureau of Statistics
7. Tim Beatty, BSci (Physics), Managing Director of Adapa Pty Ltd.
8. Prof Sharon Bell, PhD (Anthropology), Senior Program Developer, Honorary Fellow, LH Martin Institute, The University of Melbourne
9. Eva Bezac, MNuclear Physics, MMedical Physics, PhD (Nuclear & Radiation Physics), Clinical Medical Physicist, Head of Dept of Medical Physics, Royal Adelaide Hospital, President Australasian College of Physical Scientists & Engineers in Medicine
10. Richard Brown, BSci (Physics), PhD (Physics), Patent and Trade Mark Attorney, Partner at Davies Collison Cave
11. Mark Butler, BSc (Physics), PhD (Physics), DipEd, 2004 Prime Minister's Prize for Excellence in Science Teaching in Secondary Schools, Science teacher Gosford High School, NSW
12. Prof Linda Butler, formerly Head of the Research and Policy Project, ANU College of Arts and Social Sciences.
13. John Byron, BA, PhD (Humanities), Senior Advisor (Science and Research to the Minister for Innovation, Industry, Science & Research, Kim Carr
14. Associate Prof Vaughan Clarkson, BEng, Immediate past Chair of IEEE Australia Council, School of Information Technology and Electrical Engineering, University of Queensland
15. Stuart Cole, B.Comm, MBA, Business Development Executive, NICTA, Commercialisation Executive, Victorian Research Laboratory, NICTA
16. Prof Paul Dastoor, BA Natural Sci Cambridge, PhD Physics Cambridge, School of Mathematical and Physical Sciences and Director of the Centre of Organic Electronics, University of Newcastle
17. Pauline Davenport, BSc (Physics), Principal of Senior School and Science teacher, Barkly Secondary College, Tennant Creek, NT
18. Ruth Drinkwater, BSc, MBA, CEO of Australian Association of Angel Investors, Director of Women in Technology
19. Prof Andrew Dzurak, BEng, PhD (Eng), Director of UNSW's Semiconductor Nanofabrication Facility, Node Director Australian National Nanofabrication Facility, NSW Node Manager ARC Centre of Excellence for Quantum Computer Technology, Scientia Professor UNSW 2010, Electrical Engineering University of New South Wales,
20. Elizabeth Ebert, PhD (Meteorology), Research Meteorologist, Centre for Australian Climate and Weather Research, Australian Bureau of Meteorology
21. Natascha Eckert, MBA, Siemens, Munich, Germany
22. Prof Ben Eggleton, BSc (Physics), PhD (Physics), Director ARC Centre for Excellence for Ultrahigh-bandwidth devices for Optical Systems (CUDOS), Prime Minister's McIntosh Prize for Physical Scientist 2004, Scopus Young Researcher of the Year Award 2010
23. Peter Fisk, BSs (Physics), PhD Physics, General Manager Physical Metrology, National Measurement Institute

24. Cathy Foley, BSc (Physics), DipEd, PhD (Physics), Acting Chief, CSIRO Materials and Engineering, President FASTS
25. Michael Glinsky, BSci (Physics) Case Western Reserve University Ohio, USA, PhD (Physics) UC San Diego, Member of American Physical Society, EAGE, ASEG, Office of the Chief Executive Science Leader, CSIRO Earth Science and Resource Engineering
26. Alexander Gosling, Australian Industrial Research Group and Invetech, Engineer
27. Jordan Green, BEng, Electronics Engineering, MBA, Commercialisation Australia, President Melbourne Angels Inc.
28. Jacob Haimson, BSc (Physics), DSci, MD Haimson Research Corporation, Santa Clara, California, USA
29. Peter Harty, BSc (Physics), PhD (Physics), Australian Radiation Protection Society (ARPS)
30. Diana Heery, BAppliedSc, Director Science People Australia
31. Mark Hodge, BEng, PhD (Eng), CEO Defence Materials Technology Centre
32. Peter Hoffmann, Engineers Australia,
33. Michael Ilett, Year 12 Student, Glen Waverley High School, Melbourne
34. Andrew Jenkin, General Manager Technology Transfer, Technology and Innovation, Rio Tinto
35. Peter Johnston, ARPANSA
36. Kingsley Jones, BSc (Physics), Phd (Physics), Head of global thematic strategy, Macquarie Group
37. Prof Edwin van Leeuwen, BSc (Mathematics & Theoretical Physics), PhD (Mathematics), Fellow of ATSE, Clunies Ross Prize for his contributions to exploration geophysics , Centenary Medal for Services to the Australian Society in Research and Development, formerly Global Manager Exploration and Mining Technologies at BHP, currently Managing Director Norilsk Nickel, WA
38. Russel Lesley, BSc (Physics), Australian Safeguards and Nonproliferation Office,
39. Melissa Makin, BSc (Physics), PhD student, The University of Melbourne
40. Steven Meikle, BApplSc (Physics), PhD (Biomed Eng), Head of Imaging Physics Laboratory, Brain and Mind Research Institute, the University of Sydney.
41. David Mills, BSc (Physics), PhD (Physics), formerly CEO of Ausra.
42. Prof Tanya Monro, BSc (Physics), PhD (Physics), ARC Federation Fellow, 2008 Prime Minister’s Malcolm McIntosh Prize – Physical Scientist of the Year, Director Centre of Expertise in Photonics, School of Chemistry & Physics, The University of Adelaide.
43. Garry Newsom, BSc (Mathematics), PhD (Mathematics), DSTO
44. Prof Keith Nugent, BSc, PhD (Physics), ARC Federation Fellow, Director ARC Centre of Excellence for Coherent X-Ray Science, Director of Australian Synchrotron, Assistant Vice Chancellor (Sustainability), The University of Melbourne
45. John O’Sullivan, BSc (Physics), BEng, PhD Electrical Engineering, ATSE Clunies Ross Award 2010, Prime Minister’s Prize for Science 2009, CSIRO Chairman’s Medal 2009, member of IEEE, Institute of Engineers Australia, Optical Society of America, Project Leader CSIRO Astronomy and Space Science Division
46. Prof Kostya Ostrikov, DSc , PhD and MSc (Ukraine), CEO Science Leader CSIRO Material Science and Engineering, and Director, Plasma Nanoscience Centre
47. Adi Paterson, BSc (Chemistry), PhD (Engineering), CEO ANSTO, member of the South African Academy of Science and Academy of Engineering, Fellow of ATSE
48. Bill Petreski, BAppliedSc (Physics), PhD (Physics), Principal Advisor Technology Industry, Australian Industry Group.
49. Prof Steven Prawer, BSc (Physics), PhD (Physics), DSc, FAA, Director of the Melbourne Materials Institute, School of Physics, The University of Melbourne
50. Prof Anatoly Rozenfeld, MSc (Physics, Leningrad), PhD (Nuclear Physics, Kiev), Director Centre of Medical Radiation Physics, School of Engineering Physics, University of Wollongong
51. Christine Scala, BSc (Physics), PhD (Physics), DSTO

52. Len Sciacca, Chief Operating Officer, DSTO
53. Jesse Searl, Managing Director, Poseidon Scientific Instruments, Freemantle
54. Mia Sharma, BSc and DipEd, NSW Scientist of the Year for Leadership in Teaching Secondary Science 2010, Head of Science, International Grammar School, Ultimo NSW
55. Prof Margaret Sheil, BSc (Chemistry), PhD (Chemistry), CEO of ARC
56. Dr Sam Silicia, BSc. (Physics), PhD (Physics), Chief Investment Officer, HostPlus Superannuation Fund.
57. John Soderbaum, BSc (Physics), PhD (Physics), Executive Director, Acil Tasman Canberra
58. Associate Prof Marion Stevens-Kalceff, BSc (Phsyics), PhD (Physics), Deputy Director UNSW Electron Microscope Unit, School of Physics, University of New South Wales.
59. Noreen Summeth, Science teacher Teesdale Primary School Vic,
60. Prof Doreen Thomas, BSc (Mathematics), Acting Dean Faculty of Engineering, The University of Melbourne
61. Chris Walton, APESMA
62. Prof Jo Ward, PSc (Chemistry), PhD (Chemistry), Dean Faculty of Science, Faculty of Science and Engineering, Curtin University
63. Drew Williams, BEc, LLB, Aragon Capital
64. Prof Bob Williamson, AO, FAA, FRCPA, FRS, Member Royal College of Physicians London, Honorary Doctor of Medicine, Human Genetics, The University of Melbourne
65. Chris Wood, BSc, PhD (Physics) VP Santa Fe Institute, Santa Fe, USA

Appendix 7 List of written submissions

Gunther Andersson, Decadal Plan for Physics: Flinders Centre for NanoScale Science & Technology

Ken Baldwin, Decadal Plan for Physics: RSPE ANU

Bruce Hartley, Decadal Plan for Physics: Two long term problems

Bruce Hartley, Decadal Plan for Physics: Research Funding

Matthew Hole, Decadal Plan for Physics: Australian ITER Forum submission

Klaus-Dieter Liss, Decadal Plan for Physics: OZ-ERL X-Rays of the Future: An Australian Energy Recovery Linac

Dan O'Keeffe, Decadal Plan for Physics: Secondary Physics Students: How many?

Dan O'Keeffe, Decadal Plan for Physics: Secondary Physics Students: Who teaches them?

Dan O'Keeffe, Decadal Plan for Physics: Secondary Physics Students: Where do they go next?

Margaret Wegener, Decadal Plan for Physics: Education

Appendix 8 Sub-discipline reports

These are presented in Part 1

Appendix 9 Current general physics community operating environment, and needs survey

Although secondary and desk top research provide valuable information, this information is generally not current but is critical to develop insightful interview questions that address key points relevant to the current experiences of the physics community.

Further input into the development of questions to the physics community was provided through the townhall meeting process at the 2010 Physics Congress in Melbourne.

Interview process

To identify the current positives, negatives, constraints and weaknesses in the general operating environment of the Physics community, 65 in-depth interviews were conducted. The research method followed a slightly modified approach of Burchill and Hepner Brodie[102] that was developed for new product and service solution development. This approach is used in industry and business to rapidly determine the key customer requirements that need to be addressed to enable sustained competitive advantage in the market place, and has a strong track record as a process for new product and service development.

Anyone with an interest in seeing a healthy and productive Physics community was defined as a 'customer'. The term 'customer' in this context is synonymous with 'stakeholder' and the combined total of all stakeholder segments was called the "Physics community".

A critical step in this process is to ensure comprehensive coverage across all stakeholder sectors. Generally people interviewed represent different levels of seniority and different roles across different organisations in the community. This approach ensures that the relevant topics relating to people, employment and government are covered in the context of the specific stakeholders and their 'industry'. Interviewees were also granted complete confidentiality to encourage openness and frankness. The full list of interviewees is provided in Appendix 6.

The 65 people interviewed for this project included primary school students, high school students, teachers, undergraduate and higher degree students, researchers and employees across a variety of organisations that employ physicists (industry, business, government, universities, research institutes, CSIRO, DSTO, hospitals etc.) as well as self-employed physicists, with a number of them having had experience in more than one stakeholder sector and with more than one area of expertise (for example Physics and Engineering). The stakeholder interview matrix is provided in (Table 61).

Stakeholder Segments	Breadth of experience	Number of interviewees
Physics background	Tertiary degree in physics (physics major, Masters, PhD)	**32**
Economics background	Tertiary degree in economics or commerce	**3**
Engineering background	Tertiary degree in engineering	**10**
Chemistry background	Tertiary degree in chemistry	**3**
Mathematics background	Tertiary qualification in mathematics and physics	**3**
Biomedical background	Tertiary degree in biology, medicine, vet science	**6**
Law background	Commercialisation, patent attorney, consulting	**3**

[102] Burchill, G. and Hepner Brodie, C. Voices into Choices. Center for Quality of Management, (Cambridge, Massachusetts), Joiner Associates 1997

Humanities background	Government advisors, research, consulting	**3**
Dip Ed	Tertiary degree in education in addition to science degree	**4**
Management experience	Research group leaders, heads of departments and centres of excellence, deans, CEOs, Managing directors and general managers of companies,	**50**
MBA	MBA or executive MBA qualifications	**7**
Medical physics	Hospital employment, clinical research, university research, medical device industry, professional associations	**5**
Geophysics	Industry companies	**3**
Physics research	Postgraduates, post-docs, to senior academics and research leaders in universities, Centres of Excellence, CSIRO, DSTO, DMTC, ANSTO, ABS, BOM etc	**47**
Physics tertiary teaching	Undergraduate students, lecturers, professors, postgraduates	**27**
School physics education	Primary and high school teachers, secondary level students	**4**
International experience and/or employment	Substantial international work experience of several years (industry and/or research) as emigrants, immigrants, expatriates or recruits	**33**
Industry (medium and large companies)	Mining, aeronautical, automotive, (physicists employed in industry R&D and employers of physicists in these positions)	**11**
High tech industry, devices, software	Analytical and medical devices, energy technology, specialty software development	**15**
Government agencies	Modelling and measurement specialists, advisors, funding agencies	**6**
Commercialisation	People actively involved in commercialisation of physics research based IP (researchers as authors of IP, start-up and established company personnel, venture capital and angel funders	**15**
Professional/representative organisations	IEEE, AiG, ARPANSA, ARPS, AIRG, AATSE, FASTS, APESMA, Academy of Science etc	**13**
Consulting	Science focused consulting company	**2**
Employment agency	Science focused employment agency	**1**
Men		**47**
Women		**18**
Total		**65**

Table 61 Interview matrix

The second critical step is to design for each stakeholder group and the individual role and seniority within the stakeholder sector, specific interview guides. Typically the interview guide has a list of five to six main questions with a small number of probes under each question. The semi-structured interviews (using the defined interview guide as a guide and not a rigid formula) are either conducted in person or over the phone, the interviews were recorded, transcribed and then processed according to Burchill and Hepner Brodie (1997)[103]. A workshop was used to extract the key themes that emerged and develop an 'Operating

[103] Burchill, G. and Hepner Brodie, C. Voices into Choices. Center for Quality of Management, (Cambridge, Massachusetts), Joiner Associates 1997

environment map' (Appendix 9) that on one page visually describes and summarised the current operating environment of the entire Physics community.

A second workshop was used to define the needs voiced by the stakeholders and develop a Physics community 'Needs map' (Appendix 9) in the same format as the 'Operating environment map'. Both of these maps are provided in Appendix 9. The two maps were also presented to a cross-section of the interviewees to identify any discrepancies with reality in the operating environment map and for prioritising the three most important expressed needs.

Subsequently, from both maps and the requirements voiced during the town hall meetings at the 2010 Physics Congress, a list of operational requirements was developed that could be tracked against results and progress metrics, if they are acted on.

This list, of the 39 most commonly voiced requirements, was then assembled into a requirements survey made available through both a link to a Survey Monkey account and/or through an Excel spreadsheet attached to an email.

The survey was distributed through the membership lists of the AIP, APESMA, IEEE Australia and the Australasian College of Physical Scientists and Engineers in Medicine (ACPSE), and through targeted emails to all previously interviewed people, Physics Departments within the university system, CSIRO, ANSTO, DSTO and other organisations, with the request to pass it on to their networks of industry specific associations and individuals. In total, the survey was accessible to more than 3000 people.

Survey recipients were asked to rate each requirement based on its importance to them on a scale from Zero (irrelevant) to five (critically important). In a second step they were asked to rate each requirement separately on how well they thought the requirement was currently met, on a scale from Zero (not met at all) to five (100% met).

Of the 146 responses received, 127 were usable. The break-up of the 127 responses used by their organisation type was as follows:

46%	University
22%	Government and health services
10%	DSTO
8%	Primary and secondary education sector
6%	CSIRO
4%	Industry
2%	ANSTO
2%	Other

The survey results were then ranked using an opportunity index that took into consideration both importance and how well the requirements were perceived to have been already met.

The list of requirements ranked by opportunity index is provided in Appendix 9.

A high opportunity index of between 7 and 10 generally means that the requirement is both important and currently not sufficiently met. Addressing these requirements through appropriate solutions will generally lead to high satisfaction throughout the community and address shortcomings that are severe constraints. An opportunity index between 5 and 7 can indicate that the requirement is important but is already being met to some degree. There may be opportunities to do better with such middle ranked requirements. To focus on or prioritise requirements with an opportunity index below 5 is generally not a good allocation of resources (subject to better options being identified) because they are regarded as of lower importance.

The operating environment map

The current operating environment of the Physics community shows that there are many interdependencies between the sectors of the Physics community in terms of identified issues and constraints.

The Physics education sector's two 'legs' - school and higher education - are highly interdependent in terms of the competency of science and Physics teachers affecting both the attitude and capabilities of school students which in turn affects the number and capability of each year's new cohort of tertiary Physics students.

"The disconnect is that they don't understand the technology solutions like academics don't understand business needs, so there's this big gap of two people, essentially, not being able to talk to each other in the same language.

Industry representative

The tertiary education sector on the other hand influences the attitude of Physics students towards careers other than research, including teaching careers, as well as influencing the quality of teacher education. Shortcomings in either of these components of the education system are perceived to have a severe detrimental domino effect on the capabilities of the other sectors of the Physics community, the general science literacy of the public and on Australia's economy. Constraints in these two sectors are seen as equivalent to turning off a tap that has the potential to irrigate fertile fields, but instead delivers a mere trickle of muddy water.

Interviewees generally agreed that the research sector (government owned and university research providers) had the highest influence on the technology supply chain in terms of the quality and impact of their main outputs; knowledge, graduates, postgraduates trained in research processes and intellectual property that can be used by industry and business.

It was acknowledged by the majority of interviewees in all sectors, including industry and government, that funding of fundamental and basic research is essential as an indicator of an 'intelligent' and 'clever' country with scientists that are able to compete on the world stage. That breakthroughs in knowledge only occasionally leads to commercialized technology applications is not seen as an issue or something that should impact on the value and merit of undertaking and funding fundamental research.

Shortcomings and constraints in the university sector in terms of available numbers of high quality and capable graduates and trained researchers are believed to have a detrimental downstream effect on the ability of the major other Australian research providers such as CSIRO, DSTO and ANSTO to attract high quality physicists and deliver their mission based research outputs.

There are some additional difficult issues that are perceived to hold the Physics community back. One of these is the conservative approach to many aspects of research, education and industry interaction, especially of the higher education and research sector, and within this sector the 'sandstone universities' are considered to be especially problematic.

The perceived remoteness of this sector from the rest of the Physics community as believed to be mirrored by similarly conservative processes of the major funding agencies.

The impact of this doubly applied conservatism as seen as stifling the emergence and funding of the required large ideas that are needed to keep Australia at the forefront of research in the global context and also for the continued competitiveness of Australian industry companies that need inventions to emerge from Australian higher education and research.

The key findings are summarised in the following sections.

The academic research sector is currently inwardly focused.

- The research environment is perceived as unexciting and insular.

- Opportunities and talent are lost due to conservative thinking and actions.
- The research community has a negative attitude towards industry interaction.
- There are gaps and overlaps between Physics and Engineering which are managed in different ways by different universities.

The perception of the research environment across the board, but especially the academic research sector, is that it is very insular with each research group doing their own thing and furiously competing for funds. This is seen as a way of operating that has been established and ingrained over decades with little desire for change. The belief that the major funding agency of the academic sector, the ARC, as only interested in funding established ideas and research groups, is perceived to be limiting the emergence and pursuit of big risky ideas with potential high scientific or technological pay-off.

However, insular views of the world with insufficient interaction with other sectors, or even within the same sector, are not limited just to the academic environment.

As there is a specific 'group view of the world' with more frequent interactions within the Group of 8 universities, compared to the group of second and third tier universities, there are also 'group views' amongst the other research providers, research disciplines and between fundamental and applied research. For example, there is a particular CSIRO or DSTO 'attitude', an Engineering 'attitude' and a 'medical physics 'attitude', a 'fundamental research attitude' and an 'applied research attitude'.

Overall, there is a distinctly negative attitude in the academic sector to close working relationships with industry, with the only exceptions being those who had close and longer term established relationships, such as for example the University of Western Australia and Rio Tinto.

The negativity or even non-existence of industry relationships of a technology seeding science discipline such as Physics is viewed as especially puzzling by industry. Industry interviewees found the perceived disinterest and fear of interaction of the research sector to be counterproductive to the health of the entire Physics community and the economy.

Interestingly, industry interviewees do not perceive only universities as remote but also other government owned research providers such as CSIRO or NICTA.

"To create industry relationships, the rule of thumb is you're going to have to be at every meeting for the next three to five years to really build relationships with industry and gain their trust."

Industry representative

Interviewees with international experience in both the research sector and in industry stress as detrimental for both technology innovation and industry interaction, the high focus on publication based metrics and lack of balance in terms of impact metrics. This makes it difficult, if not impossible, for researchers to do research, commercialise, build start-up companies to successful exits and then re-enter the research sector again.

The lack of excitement about new ideas, new technologies and cross-fertilisation from other disciplines and industry is seen as the cause for a drift to more exciting overseas research destinations or for an exit into more lucrative and fast paced industry positions.

In the academic sector, due to the segmentation of the sciences into the fundamental disciplines of Physics, Chemistry etc and the more applied sciences such as Engineering, many interviewees observed a 'chasm' or a 'divide' between Physics and Engineering, Physics and Chemistry, Physics and Biology or Medicine or any other related discipline. The most severe divide is perceived between Physics and Engineering, especially in those universities in which Physics and Engineering are based in different faculties.

"From my experience, academia is looking towards industry engaging them, and industry will never do that; it's academia who needs to engage industry"

Industry representative

These chasms or divides are seen as detrimental to cross-disciplinary research and to the initiation of collaborations between postgraduates in different disciplines, which could lead to new ideas.

Divides between Physics and other disciplines are not seen to exist in the government owned research providers such as CSIRO, the Bureau of Meteorology and DSTO as physicists in these organisations are employed in specific functions that are not based on their type of degree.

"I didn't want to leave home, and there were good options available at the ANU.
I am still in Canberra now. I've never wanted to live anywhere else; I don't have the travel bug, I am very close to my parents, I don't make friends easily, I wanted to stay near the friends I had"
Government service representative

Job security is a major problem in retaining talented researchers in academia and in research institutions

- High calibre Physics talent is emerging but there are limited opportunities for advancement in Australia
- There is no long-term job security in research for most people

Job security is seen as a major problem in all research provider organisations, not only at universities. The difficulties in attracting and retaining highly qualified researchers to research positions is seen as a major cause for concern. The issue of the 'eternal postdoc' is seen as the major cause of women starting families later in life than they would like to, for staff, especially women, leaving research careers, and for the low attractiveness of a career in Physics research for younger people.

It is acknowledged that currently there is a young cohort of high calibre Physics talent emerging but the lack of tenured positions available makes it likely that at least some of these people will leave again for overseas positions.

Employment opportunities exist for graduates outside academia, but are difficult to match up.

- There are employment opportunities for Physics graduates with sound theoretical knowledge and practical skills
- The quality of interaction between potential employers and academia limits identification of job opportunities

There are many job opportunities for new Physics graduates in many industries and in teaching in schools (see chapter on employment destinations). However, graduates and postgraduate and industry based interviewees clearly indicated that undergraduates and new graduates are quite 'clueless' about what is possible in terms of careers and what basic skills they needed to bring to the table to be attractive to future employers besides their Physics skills.

Employers across the board are satisfied with the basic science skills of new graduates but many prefer research training, demonstrated by a Masters or a PhD degree, as long as the extended timeframe for getting that degree does not just lead to more narrow knowledge instead of more depth and breadth.

A shortcoming of recent graduate cohorts entering industry and business is seen as unwillingness to move away from their current place of study or from capital cities.

Lack of team working skills and experimental skills are mentioned, especially if graduates and postgraduates come from higher education institutions with low numbers of Physics graduates and with small research groups (which impedes them getting experience working in large groups and teams).

Lack of understanding of the contribution of physics to society -- specialist teaching is limiting interest in physics in schools.

- The desire for a Physics career is shaped early, and often by positive school-age experiences
- The quality of high school Physics teaching is limited by lack of specialist Physics teachers
- Physics' contribution to modern society is fundamental but not well recognised

One of the most critical bottlenecks and constraints on the health of the Australian Physics community is the very limited quality of Physics teaching throughout high schools, based on the lack of specialised Physics teachers that have graduated as Bachelors of Science with a major in Physics. The limited understanding of the subject of Physics does not allow non-qualified teachers to explain complex topics and principles in an age appropriate way that does not turn children off Physics permanently.

As Physics is seen as difficult and the attitude of students towards Physics and its enabling science topic Mathematic slips already between age 10 and 14 (see Section 3.11 on the School education sector), instilling a positive attitude towards Physics requires teachers themselves being enthusiastic about this subject.

Many of the interviewees stressed that they had made up their minds early about studying Physics and often mentioned an enthusiastic or inspiring teacher or a specific event such as the moon landing or the launch of Sputnik in facilitating that decision. The lack of enthusiasm for studying Physics at school leads to small Physics classes in the senior years and low entry numbers into university as school students also do not have good information on what they could do at the end of their Physics degree.

Physicists in all sectors stress that there is no unified professional 'image' that they can portray to school students or the general public as there is no accrediting body as for example for professional engineers. No such process exists for Physics.

It became clear throughout the interview process that the opportunity to portray the study of Physics at school and in tertiary institutions as the springboard to many lucrative professions is not taken up anywhere in the Physics community. Instead it is portrayed as a 'foundational' science and mainly as something that is pursued as a research career.

"Our company believes that the graduates, for their education, need to move around; getting people out of the cafés in Carlton – that is an issue for us."

Multinational industry representative

The achievements of physicists and the technology advances made over the last 50 years or even the last 20 years and how they have changed society's daily lives for the better are not visible or accessible to the general public, parents and school students alike. This in turn does not portray a positive picture of physicists or a career in a physics based industry in Australia. Several interviewees and participants in town hall meetings believe that in the view of the public their physics career is seen less desirable than an engineering career.

Administrative and funding processes are negatively impinging on research efficiency and productivity.

- Academics experience an increasing burden of administrative and managerial activities
- The research funding system does not support cross-disciplinary research
- The funding system does not fully cover the cost of research projects

"I decided to become a physicist specifically at age 15. I had an amazing physics teacher at school and just decided then that I wanted to study physics… I had previously wanted to be a musician and I was on a music scholarship at school, but at that point I decided I wanted to be a physicist"

University Professor

Constraints due to the funding system and administrative overload are not specific to just the Physics discipline and Physics research providers.

Although other research providers and industry report increasing administrative burden on researchers they are more likely to accept that as part of their jobs in today's globally competitive environment.

Interviewees in universities note an increased amount of administrative burden related to reporting but especially related to the funding processes of Australian funding agencies, and in particular to ARC processes.

The major constraints on researcher productivity is seen in the loss of productivity of at least 20% in those university Physics departments in which many researchers apply for ARC discovery grants. The most commonly mentioned time spent on writing applications to funding agencies is given as two months per researcher per year. Given that grant funding does not cover the full cost of research there is a mixed attitude to grants: 'We need it as it is prestigious to get an ARC grant – but it costs us money to get one. The more we get the more we go into the red'.

The discipline panel based selection process is seen as limiting the pursuit of big ideas at the borders of disciplines and cross disciplinary research and the lack of agility of the funding process is extending the response time to good ideas to such a degree that the time from application to employment on a research grant is delayed and the competitive advantage of the idea is lost.

Physics is a major contributor to the global research competitiveness of Australian research providers -- some of the capabilities are world class.

Most interviewees agree that Physics is a major contributor to the global competitiveness and image of Australian research and research providers overall. The contribution of Physics to other research disciplines is seen as substantial. Interviewees across the board value the current quality of research infrastructure but worry about continuance of sufficient infrastructure funding and upgrades so that this current competitiveness and relevance is not lost.

Researchers in particular worry that infrastructure that currently is leading edge and only affordable by a few organisations in Australia, such as super-computing and nano-material fabrication facilities for example, in the future will become 'ordinary must-have' infrastructure that has to be available locally in multiple Australian research organisations.

Translation of research outputs into technology through commercialisation is a major problem area.

The issue of commercialisation of research results is identified by both the research sector and industry as a major constraint in terms of incentives, motivation, metrics, expertise and processes. Although this issue is seen as important it was not included into the physics community operating environment and needs maps due to the fact that this is an issue that is common to all research disciplines and research organisations, and not only physics as a discipline.

The interviews with individuals that had been involved with commercialisation, either successfully or unsuccessfully show that the process has many and less than optimal outcomes. The discussion of case studies of successful commercialisation outcomes with the physicists that were responsible for the initial research output leading to a technology that reached the market show that each case met avoidable hurdles and took a more convoluted path to market than logically necessary, and several only succeeded due to the extreme persistence and tenacity of the researcher.

"The grants are so long and difficult to write; that's something which makes me not so excited about trying to become an academic. *My supervisor spends a third of the year, each year writing grants, that doesn't sound like heaps of fun. I'd rather spend my time doing research"*

PhD student

The physics community needs map

The Physics community needs map is provided in Appendix 9.

Focused consolidation is needed to maintain long-term international excellence.

- The culture of excellence in Physics must be maintained
- The tertiary sector needs to be rationalised to maintain delivery of high quality education and research training.

This block of needs was given the highest priority by interviewees based mainly on the need for at least maintaining but better still, increasing the current state of excellence, not only in research but also at a systemic level throughout the Physics community and all its processes, from school education through to commercialisation of research results and reaching the full potential of available talent.

Remaining at the highest level of excellence in research is seen as of utmost importance. Only the highest level of excellence in research will attract both national and international funding by government funding agencies and industry over the next decade and beyond. It was made clear by industry interviewees that industry has access to research talent and infrastructure globally and that they source the best expertise available, regardless of location.

"We have very tough selection criteria for strategic long term relationships with universities, for example excellence in research; good international reputation; high degree of interdisciplinary teams but a proximity to our locations as well; then it has to be a top university for our talent acquisitions"

Multinational industry representative

An obstacle to reaching this level of excellence is seen to be a perceived decline in the quality of education of school students in Physics. This primarily attributed to the lack of qualified Physics teachers and an uninspiring and irrelevant Physics curriculum, which in turn limits the pool of high quality university entrants.

A further obstacle to reaching systemic excellence is seen in the potential disruption of a predictable level of funding for research as wide fluctuations in funding that would most likely result in the depletion of the Australian Physics talent pool through migration into overseas research institutions.

The requirements related to maintaining a systemic culture of excellence in physics are listed in Table 62.

Customer Requirement or Desired Outcome	**Importance: Rank from 0 = Irrelevant to 5 = Critical**	**Satisfaction: Rank from 0 = Not met at all to 5 = 100% met**	**Opportunity Ranking: 10 = Must do through should do, Nice to do, to 0 = Forget it**
A high standard physics curriculum in schools that is the floor of what can be delivered and not the ceiling (do not water down the current content), and is delivered by teachers with a tertiary degree in physics and/or mathematics	4.45	1.50	7.39
Maintenance of long term consistency of current funding levels to the physics disciplines	4.43	2.12	6.74
Increased number of longer term research fellowships (six years plus) to retain high calibre early career women in the profession during their child bearing years	3.72	1.51	5.94
Mechanisms for facilitating re-entry of high calibre researchers out of industry careers into academic careers, to re-invigorate physics sub-disciplines that are currently in decline due to the loss of top post graduates and post-docs into highly paid industry positions	3.66	1.89	5.44
University guidelines that make physics and advanced mathematics compulsory prerequisites for studying physics at university, regardless of tertiary entry score	3.56	2.00	5.12

Increase of PhD course duration from 3.5 to 4 years	3.02	1.94	4.10

Table 62 Requirements related to culture of excellence ranked by opportunity score (Opportunity scores above 5.34 shaded yellow).

There is debate about whether increasing excellence requires focused consolidation in terms of closing Physics departments in regional universities but the requirements survey does not support this consolidation. There is support, however, for collaboration between universities in the same location to achieve sufficient depth and breadth and eliminate gaps in education.

The list of requirements related to potential rationalisation of the tertiary sector to maintain delivery of high quality education and research training is found in Table 63.

Customer Requirement or Desired Outcome	**Importance: Rank from 0 = Irrelevant to 5 = Critical**	**Satisfaction: Rank from 0 = Not met at all to 5 = 100% met**	**Opportunity Ranking: 10 = Must do through should do, Nice to do, to 0 = Forget it**
Collaboration between universities in the same location (e.g. capital cities and close by regional centres) to fill gaps in teaching and increase the depth and breadth of undergraduate education and honours degrees at the second and third tier universities	3.57	1.71	5.44
Increase the depth and breadth of education of physics graduates	3.80	2.42	5.19
Reassessment of the physics higher education courses across all universities so that a complete high quality physics education, research education and service teaching program is provided.	3.82	2.63	5.00
Consolidation of the research activities within smaller universities so that they focus on their current research strengths and relinquish other non-strength research areas to other universities	2.86	2.56	3.17

Table 63 Requirements relating to consolidation and collaboration within the tertiary sector, ranked by opportunity score. (Opportunity scores above 5.34 shaded yellow).

The physics research community needs to implement more flexible career structures and paths.

- There is need to address the loss of female talent, especially in the early research career years and support their career progression
- There is a need to support temporary entrepreneurial engagements without prejudicing research career progression

There is strong awareness in the Physics community that the career structures within the higher education and the research sector as a whole are quite rigid, prescribing specific steps. The current attitude towards preference of research only careers without easy exit and entry ramps to and from industry or to and from family commitment based career breaks has led to funding agencies and research organisations implementing Research Opportunity and Performance Evidence (ROPE) guidelines to prevent researcher disadvantage on the basis of gender, family commitments and industry activity.

The interview process and the requirements survey both show that the Physics community is generally aware that the gender balance is severely skewed towards men in all sectors. The requirements survey shows that enforcement of ROPE guidelines and reporting on equity measures attained low opportunity scores. Generally female respondents to the survey rank equity highly in importance and are less satisfied with how well equity is achieved, whilst male respondents either rate it as not important or already achieved or both not important and already achieved to a high degree. This inconsistency in response based on gender and the gender imbalance in survey respondents overall (77% male and 23% female) led to a low opportunity index for achieving successful implementation of equity based concepts beyond achieving equity in teaching and removal of competition between established and early career researchers in funding programs (Table 64).

Customer Requirement or Desired Outcome	**Importance: Rank from 0 = Irrelevant to 5 = Critical**	**Satisfaction: Rank from 0 = Not met at all to 5 = 100% met**	**Opportunity Ranking: 10 = Must do through should do, Nice to do, to 0 = Forget it**
Equitable balance of work load, teaching and contact hours for male and female physics staff at all levels	3.99	2.34	5.64
Funding programs for early and mid-career level researchers that cannot be accessed by senior career researchers	3.85	2.33	5.37
Equity initiatives in each physics department to report and compare the ranking of each physics department according to equity	2.87	2.13	3.62
Enforcement of ROPE guidelines in funding schemes and at research organizations when selecting employment candidates	2.95	2.51	3.40

Table 64 Requirements relating to the need to address equity measures, ranked by opportunity score (Opportunity scores above 5.34 shaded yellow).

It is clear that the lack of transparent and equitable metrics and reward systems that not only measure excellence based on publications is seen as worth addressing, in the context of maintaining excellence.

Similarly there is support for utilising external new ideas and talent to invigorate the Physics sub-disciplines and there is slightly higher support for facilitating temporary entrepreneurial engagements without prejudicing research career progression (Table 65) than for enforcing gender equity. However, there is currently low support for enforcing the ROPE guidelines to support entrepreneurial activity.

The low importance, satisfaction and opportunity scores relating to industry interaction and Key Performance Indicators (KPIs) for tracking industry interaction are indicative of the current cultural attitude of the higher education and research sector towards industry interaction and collaboration.

These low scores indicate that, without implementing metrics that reward retention and equitable participation (as opposed to penalties for non-compliance), changes will be met with resistance in the higher education and research sector.

Customer Requirement or Desired Outcome	**Importance: Rank from 0 = Irrelevant to 5 = Critical**	**Satisfaction: Rank from 0 = Not met at all to 5 = 100% met**	**Opportunity Ranking: 10 = Must do through should do, Nice to do, to 0 = Forget it**
Transparent and equitable metrics and reward systems that measure and reward excellence at all stages of the innovation continuum from fundamental research, applied research, teaching, entrepreneurial activity to working in industry research in order to capture and retain people with the highest skill levels in each of these areas	3.98	2.13	5.83
Mechanisms for facilitating re-entry of high calibre researchers out of industry careers into academic careers, to re-invigorate physics sub-disciplines that are currently in decline due to the loss of top post graduates and post-docs into highly paid industry positions	3.66	1.89	5.44
Develop budget models that allow post-docs to develop closer relationships with industry to attract national and international research funding for fundamental and applied research and improve their income security	3.54	2.02	5.06

Inclusion of entrepreneurial activity (time in a start-up company regardless of success of failure) or employment in industry research as a positive factor under the 'Research Opportunity and Performance Evidence (ROPE)' guidelines of funding agencies, HIRD and government research organisations	3.37	1.86	4.88
Develop models for effective collaboration between national and international industry companies and Australian research organisations	3.36	2.10	4.61
Develop mutually agreed Key Performance Indicators (KPIs) for industry/business and research organization interaction success	2.68	1.81	3.55

Table 65 Requirements related to the need to support temporary entrepreneurial engagements without prejudicing research career progression, ranked by opportunity score (Opportunity scores above 5.34 shaded yellow).

The physics research community needs to embrace applied research and commercial relationships.

- The Physics community needs to ascribe greater value to applied Physics.
- Closer and longer-term relationships between the Physics community and industry need to be developed in targeted areas.

The Physics community is generally aware that the siloed approach of the sub-disciplines is detrimental to portraying a common and inspiring image of Physics and also for fostering collaborative and cross-disciplinary research, even amongst the Physics sub-disciplines.

A somewhat 'elitist' attitude amongst some of the academic sector of fundamental physics being 'real physics' and applied Physics being more like 'Engineering' is perceived as not adding value by most survey respondents. Requirements related to eliminating hurdles that are connected to translating applied research results into technologies are not seen as providing sufficient incentives for change at this stage (Table 66).

Customer Requirement or Desired Outcome	**Importance: Rank from 0 = Irrelevant to 5 = Critical**	**Satisfaction: Rank from 0 = Not met at all to 5 = 100% met**	**Opportunity Ranking: 10 = Must do through should do, Nice to do, to 0 = Forget it**
Mechanisms that demonstrate that the Physics community is becoming inclusive of the sub-disciplines already split off into their own communities (e.g. geophysics and medical physics), the newly defined sub-disciplines (e.g. econophysics. neurophysics, psychophysics etc.) and the more applied sub-disciplines (e.g. photonics and optics), to avoid inward focus and foster cross-sub-discipline research	3.78	2.22	5.34
Elimination of penalties in career progression for researchers working on applied physics research compared with fundamental research	3.81	2.39	5.23
Systematic evaluation of commercialisation processes of US HERD organisations that have a high success rate in commercialization to improve the effectiveness of the commercialisation processes of Australian physics departments	3.00	1.67	4.34
Co-location of fundamental and applied physics research groups working in the same research area	3.37	2.48	4.26

Table 66 Requirements relating to embracing applied physics research and commercial relationships, ranked by opportunity score (Opportunity scores above 5.34 shaded yellow).

Requirements relating to establishing longer term relationships between the Physics research community and industry in targeted areas are only seen as an opportunity if they are related to 'outbound' marketing of

Australian Physics research. Related systemic requirements to address internal constraints to closer relationships are not seen as opportune at this stage.

The priority ranking of the blocks of needs by a sample of interviewees, that included a number of industry based interviewees, shows that on a priority list this block of needs with its underlying requirements has much lower priority to the respondents. This most likely reflects that only 4% of respondents work in industry.

Customer Requirement or Desired Outcome	**Importance: Rank from 0 = Irrelevant to 5 = Critical**	**Satisfaction: Rank from 0 = Not met at all to 5 = 100% met**	**Opportunity Ranking: 10 = Must do through should do, Nice to do, to 0 = Forget it**
Active promotion of Australian physics research to national and international industry and businesses as a viable alternative to overseas research organisations that are currently used by industry to solve their fundamental and applied research problems	3.99	2.04	5.94
Develop budget models that allow post-docs to develop closer relationships with industry to attract national and international research funding for fundamental and applied research and improve their income security	3.54	2.02	5.06
Inclusion of entrepreneurial activity (time in a start-up company regardless of success of failure) or employment in industry research as a positive factor under the 'Research Opportunity and Performance Evidence (ROPE)' guidelines of funding agencies, HIRD and government research organisations	3.37	1.86	4.88
Develop models for effective collaboration between national and international industry companies and Australian research organisations	3.36	2.10	4.61
Systematic evaluation of commercialisation processes of US HIRD organisations that have a high success rate in commercialisation to improve the effectiveness of the commercialisation processes of Australian physics departments	3.00	1.67	4.34
Develop mutually agreed Key Performance Indicators (KPIs) for industry/business and research organization interaction success	2.68	1.81	3.55

Table 67 Requirements relating to closer and longer-term relationships between the Physics community and industry in targeted areas, ranked by opportunity score (Opportunity scores above 5.34 shaded yellow).

Physics needs to be invigorated by tackling big problems using more courageous and adventurous approaches.

- Physics needs to be invigorated by tackling big problems using more adventurous approaches
- Research organisations need to implement mechanisms that make working across disciplines easier

It is generally agreed that the highest payoffs in terms of new knowledge and in new technologies will come from cross-disciplinary research programs and bringing in talent from outside conventional sources. However, there is also support for implementing changes to funding agency processes to facilitate high risk, high payoff ideas being pursued and for better mentoring of young talent in all research organisations (not only universities) (Table 68).

Customer Requirement or Desired Outcome	**Importance: Rank from 0 = Irrelevant to 5 = Critical**	**Satisfaction: Rank from 0 = Not met at all to 5 = 100% met**	**Opportunity Ranking: 10 = Must do through should do, Nice to do,**

			to 0 = Forget it
Effective mechanism for funding of cross-disciplinary postgraduate research projects (e.g. physics – engineering, physics – chemistry – engineering, physics – mathematics – computing etc.) to foster new ideas and “out of the box” thinking and to sow the seeds for interdisciplinary post-doc research	4.09	2.20	5.97
Development of interdisciplinary funding models between NH&MRC, ARC, industry funding agencies and research organisations, to foster research that is currently difficult to access funding for, as it does not fit with current funding agency funding rules	3.78	1.64	5.91
Mechanisms for facilitating re-entry of high calibre researchers out of industry careers into academic careers, to re-invigorate physics sub-disciplines that are currently in decline due to the loss of top post graduates and post-docs into highly paid industry positions	3.66	1.89	5.44
Effective and equitable mentoring schemes in Physics departments (research organisations undertaking physics research) including open door policies so that postgraduates and students can be more effectively mentored and are able to interact more easily with researchers (at all levels) in their organisations	3.95	2.71	5.19
Within funding agencies, development of at least one interdisciplinary panel of experts in addition to the current discipline panels	3.41	1.89	4.92

Table 68 Related requirements related to research tackling bigger problems with more adventurous approaches by opportunity score (Opportunity scores above 5.34 shaded yellow).

Requirements related to making cross-disciplinary and collaborative work easier are generally seen to provide opportunities for improvement and payoff in the future.

Customer Requirement or Desired Outcome	**Importance: Rank from 0 = Irrelevant to 5 = Critical**	**Satisfaction: Rank from 0 = Not met at all to 5 = 100% met**	**Opportunity Ranking: 10 = Must do through should do, Nice to do, to 0 = Forget it**
Effective mechanism for funding of cross-disciplinary postgraduate research projects (e.g. physics – engineering, physics – chemistry – engineering, physics – mathematics – computing etc.) to foster new ideas and “out of the box” thinking and to sow the seeds for interdisciplinary post-doc research	4.09	2.20	5.97
Professors and senior academics to become positive role models and promote a balanced and more positive view of other physics related career options in addition to straight research careers (e.g. school teaching, business, government, industry)	3.79	2.12	5.46
Mechanisms that demonstrate that the Physics community is becoming inclusive of the sub-disciplines already split off into their own communities (e.g. geophysics and medical physics), the newly defined sub-disciplines (e.g. econophysics, neurophysics, psychophysics etc.) and the more applied sub-disciplines (e.g. photonics and optics), to avoid inward focus and foster cross-sub-discipline research	3.78	2.22	5.34
Elimination of penalties in career progression for researchers working on applied physics research compared with fundamental research	3.81	2.39	5.23

Effective and equitable mentoring schemes in Physics departments (research organizations undertaking physics research) including open door policies so that postgraduates and students can be more effectively mentored and are able to interact more easily with researchers (at all levels) in their organisations	3.95	2.71	5.19
Reassessment of the physics higher education courses across all universities so that a complete high quality physics education, research education and service teaching program is provided	3.82	2.63	5.00
Co-location of fundamental and applied physics research groups working in the same research area	3.37	2.48	4.26

Table 69 Requirements related to research organisations needing to implement mechanisms that make working across disciplines easier, ranked by opportunity score (Opportunity scores above 5.34 shaded yellow).

The higher education and research system needs to invest in engagement with the school sector at all levels to inspire interest in physics.

The requirements relating to investing into mechanisms for better engagement of the higher education and research system with the school sector found high support throughout the sample of interviewees and both the school and higher education and research sector (Table 70).

Although the requirement relating to bridging courses as a short term initiative for improving the capabilities of teachers without Physics qualifications is highly supported, the underlying requirement that is currently unmet is the availability of easily and instantly accessible material that these teachers can find and use to upgrade both their knowledge and their confidence in applying this knowledge in the class room.

Solutions such as bridging courses are seen as only a stop-gap measure to overcome extreme problems that exist now. A more solid and long lasting solution would be to require and provide appropriate training schemes and associated pay structures for Physics (and Mathematics) teachers that make this profession more attractive to new Physics graduates again.

Opportunities are seen as high for developing materials for the general public, teachers, and school students on what Physics is, its benefits and potential career paths in the future, and portraying of Physics, not as a set of numerous sub-disciplines, but as a common large discipline that achieves impact in a global context. Initiatives to develop solutions in this space will be supported by the majority of the Physics community.

"At age 9 or 10 I worked out the things that I enjoyed doing, which was messing about, trying to understand how things worked, whether that was models or rockets, or electronic bits and pieces. Because that actually was called physics, then I realised that that was what I wanted to do"

University professor

Customer Requirement or Desired Outcome	**Importance: Rank from 0 = Irrelevant to 5 = Critical**	**Satisfaction: Rank from 0 = Not met at all to 5 = 100% met**	**Opportunity Ranking: 10 = Must do through should do, Nice to do, to 0 = Forget it**
Instantly accessible bridging courses for science teachers that currently have no qualifications in physics	3.98	1.43	6.54

Mechanisms for kindergarten and primary school teachers to access instructions for experiments that can be easily constructed in any kindergarten and primary school environment with common ingredients to enthuse kindergarten and primary school age children about physics and science	3.92	1.80	6.04
A promotional program to provide the public, teachers, and school children with a clear picture of what physicists and their sub-disciplines do (their professions, activities, responsibilities and achievements)	4.15	1.91	6.39
The physics sub-disciplines, together with the 'mainstream' physics disciplines to develop a united professional image that promotes the importance and impact of both fundamental and applied physics, and employment opportunities and career paths within all sub-discipline groups, to the community	3.85	1.75	5.95
A "career description" for typical physics career paths to ensure that school children, their parents and graduates have a clear picture of some of the physics career possibilities to help in their career decision making process	3.82	1.73	5.91
Evaluation of the effectiveness of university and other research organisation based outreach programs that aim to increase the intake of first year physics students in all universities	3.69	2.05	5.34
Promotional program to continuously promote physics as the springboard to vocational applications and careers	3.53	1.79	5.26

Table 70 Requirements relating to better engagement with the school sector, ranked by opportunity score (Opportunity scores above 5.34 shaded yellow).

Undergraduate physics needs to be made more attractive by giving it a higher vocational emphasis.

- For graduate employability there needs to be a better match between course content and employer requirements
- The education of graduates needs to include more practical experience to increase employability

A unified image of Physics, the development of information materials for undergraduates about potential professional directions they could take instead of only promoting research careers is regarded as providing opportunities for young physicists to broaden their view towards other employment opportunities outside the research sector. A major role in this endeavour will need to be played by senior academics.

Improved interactions between the higher education and research sector and industry will provide additional benefits to the higher education sector in terms of developing up to date understanding of industry and business needs in terms of skills and talent.

Industry's perception of undergraduate and postgraduate training as moving away from solid experimental education is seen as unfounded by the higher education sector in particular (Tables 71 and 72).

Customer Requirement or Desired Outcome	**Importance: Rank from 0 = Irrelevant to 5 = Critical**	**Satisfaction: Rank from 0 = Not met at all to 5 = 100% met**	**Opportunity Ranking: 10 = Must do through should do, Nice to do, to 0 = Forget it**
Easily accessible and up to date information for physics graduates on potential employers that have a track record of employing physics graduates	4.00	1.99	6.01

The physics sub-disciplines, together with the 'mainstream' physics disciplines to develop a united professional image that promotes the importance and impact of both fundamental and applied physics, and employment opportunities and career paths within all sub-discipline groups, to the community	3.85	1.75	5.95
Professors and senior academics to become positive role models and promote a balanced and more positive view of other physics related career options in addition to straight research careers (e.g. school teaching, business, government, industry)	3.79	2.12	5.46
Increase the depth and breadth of education of physics graduates	3.80	2.42	5.19
More hands-on experimentation experience opportunities for undergraduates whilst maintaining a very high standard of fundamental physics training	3.90	2.71	5.10
Mandatory undergraduate practical work experience in industry or businesses that employ physicists	2.75	1.33	4.17

Table 71 Requirements related to better matching between undergraduate and postgraduate course content and employer requirements, ranked by opportunity score (Opportunity scores above 5.34 shaded yellow)

Customer Requirement or Desired Outcome	**Importance: Rank from 0 = Irrelevant to 5 = Critical**	**Satisfaction: Rank from 0 = Not met at all to 5 = 100% met**	**Opportunity Ranking: 10 = Must do through should do, Nice to do, to 0 = Forget it**
Increase the depth and breadth of education of physics graduates	3.80	2.42	5.19
More hands-on experimentation experience opportunities for undergraduates whilst maintaining a very high standard of fundamental physics training	3.90	2.71	5.10
Mandatory undergraduate practical work experience in industry or businesses that employ physicists	2.75	1.33	4.17

Table 72 Requirements related to the education of graduates and the needs to include more practical experience to increase employability, ranked by opportunity score (Opportunity scores above 5.34 shaded yellow).

The physics community needs to explore the relevance of its performance metrics.

The currently high focus on predominantly publication related metrics as the basis for performance assessment in the higher education and the research sector in general is not regarded as balanced in today's research and industry and business environment. This is an unexpected finding in light of the fact that most survey respondents were drawn from research organisations.

Despite this, because publication is a common and globally accepted method of measuring research quality, an excellent track record for individuals, research organisations and the discipline as a whole in terms of publication output, is seen as important by the higher education, the research sector and also by industry.

However, it is felt that the predominance of this metric at the cost of using other impact metrics as well, is holding industry back from investment in research organisations in Australia. Even more importantly it is argued that it holds back entrepreneurialism and technical innovation in Australia. There is general support for finding a better balance of metrics throughout the Physics community (Table 73).

Customer Requirement or Desired Outcome	**Importance: Rank from 0 = Irrelevant to 5 = Critical**	**Satisfaction: Rank from 0 = Not met at all to 5 = 100% met**	**Opportunity Ranking: 10 = Must do through should do, Nice to do,**

			to 0 = Forget it
Transparent and equitable metrics and reward systems that measure and reward excellence at all stages of the innovation continuum from fundamental research, applied research, teaching, entrepreneurial activity to working in industry research in order to capture and retain people with the highest skill levels in each of these areas	3.98	2.13	5.83
Inclusion of entrepreneurial activity (time in a start-up company regardless of success of failure) or employment in industry research as a positive factor under the 'Research Opportunity and Performance Evidence (ROPE)' guidelines of funding agencies, HIRD and government research organisations	3.37	1.86	4.88
Enforcement of ROPE guidelines in funding schemes and at research organisations when selecting employment candidates	2.95	2.51	3.40

Table 73 Requirements related to improving the relevance of performance metrics, ranked by opportunity score (Opportunity scores above 5.34 shaded yellow).

Survey conclusions

The survey of the wider physics community on a number of requirements mirrored to a large degree the conservative approach that was established in the analysis of the operating environment.

However, it was agreed that the physics community needs to maintain excellence, re-energize through new approaches and engaged more broadly with society.

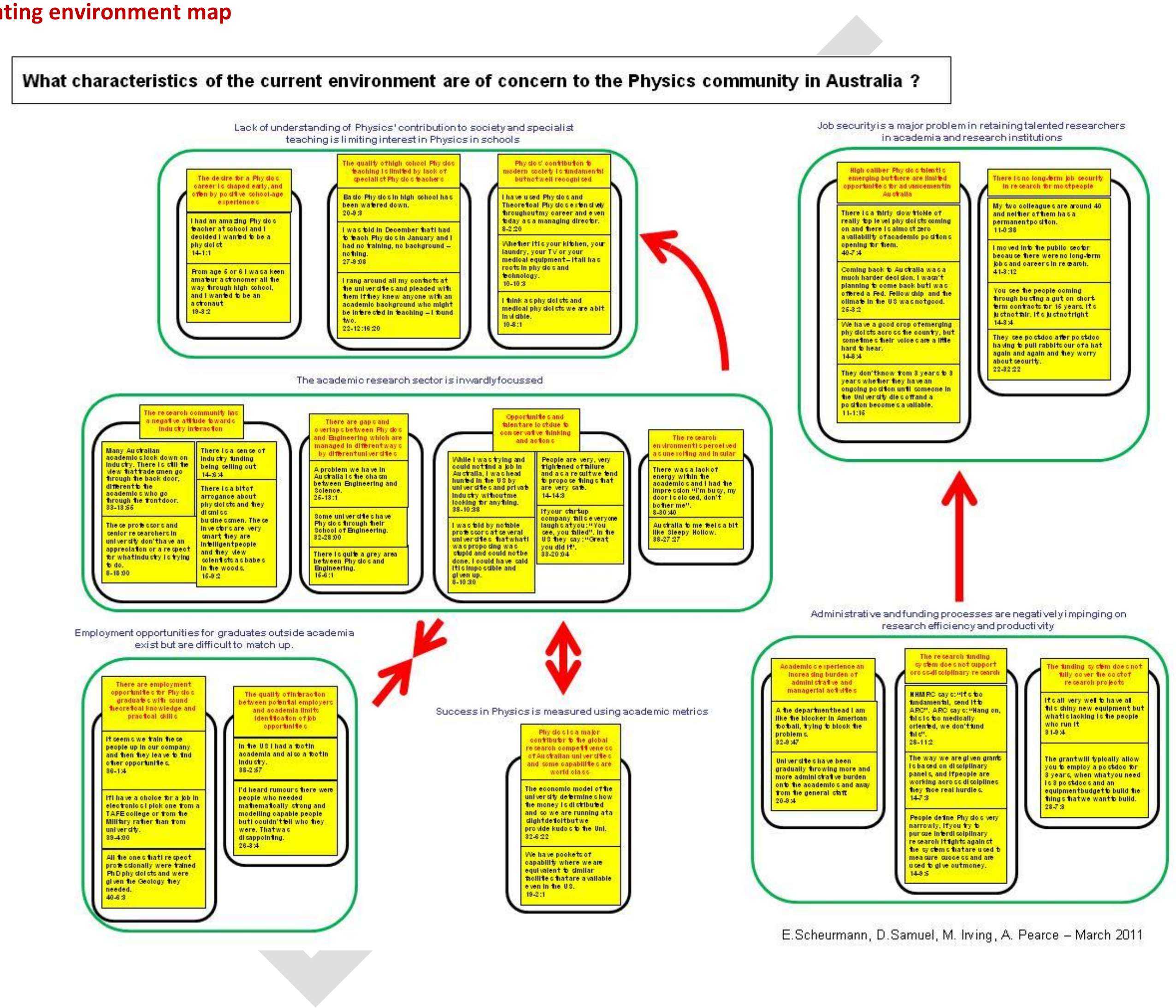
A clear outcome from the interview process, the development of the maps and the survey process on the requirements is the identification of the relatively rigid boundaries between the individual stakeholder sectors, and especially between the higher education and research sector and its 'customer' stakeholder segments. Although there is generally good will by all parties, the hurdles to closer interactions are perceived to be difficult to overcome without external enforcement of rules and a broader metric set.

Many of the obstacles to effective and efficient use of research and education funding that the physics community believes will affect their future prosperity and viability are seen to be of lower importance by the non-research focused Physics community. Similarly, a further indicator for maintaining the current status quo appears to be reluctance to implement any changes to systems and processes that could have an effect on the current gender balance in Physics.

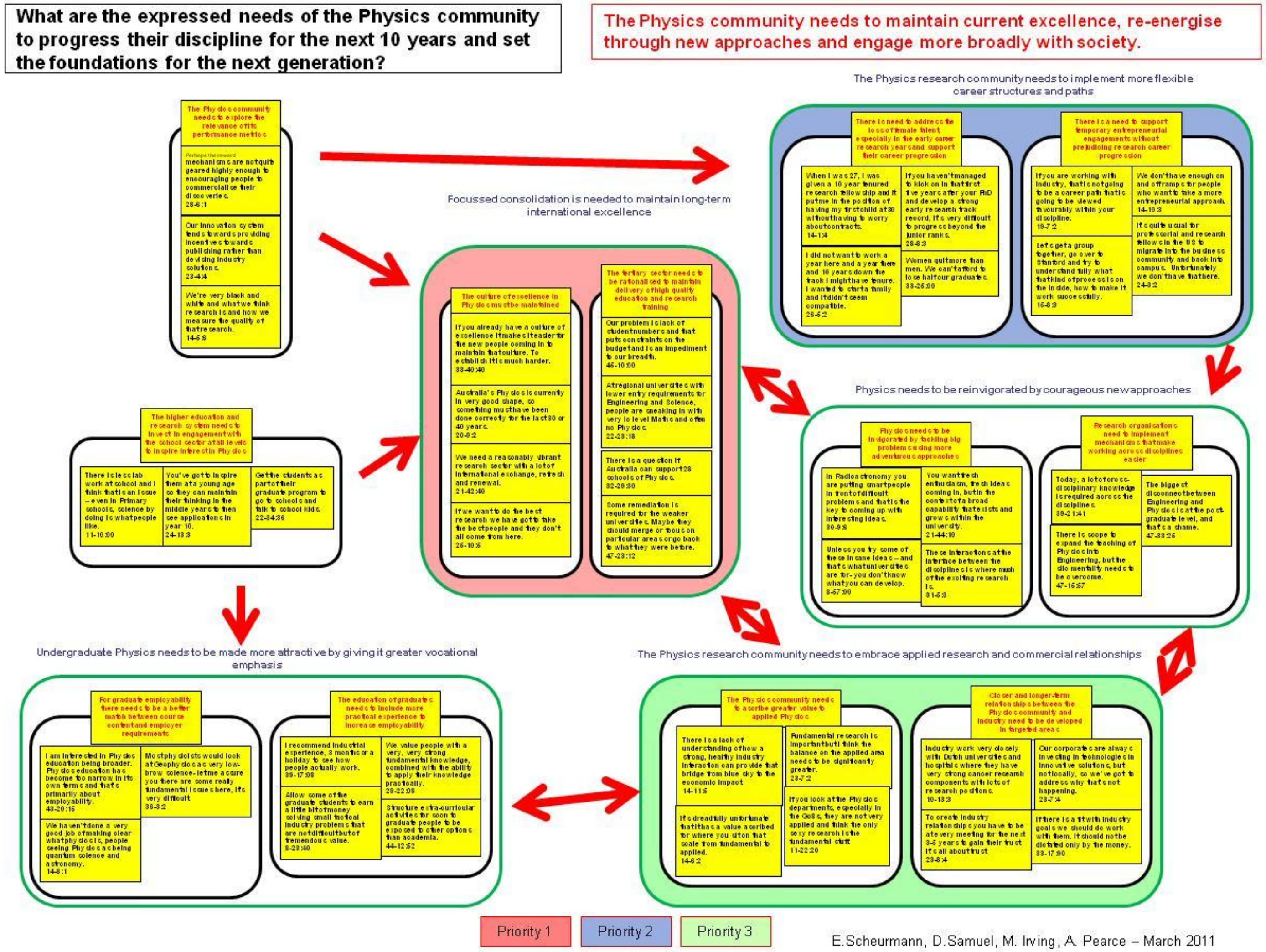
The relatively low importance given by the research sector (especially academia) to the interaction between the industry/business sector and the research sector will make it difficult to set up fruitful interactions. Potentially a useful step will be to agree on expectations of both of these physics stakeholder sectors.

The international comparisons of school student performance shows that currently Australian school students are not below international average, but a downwards trend is already evident. The focus on the school curriculum by survey respondents as their number one opportunity for change identifies a pending and potential severe supply issue for physics. Other bottle necks, such, as insufficient Physics teacher training and a lack of a clearly understandable 'picture' of physics as an attractive option in the eyes of the public, of school students and their parents as well as employers also exist. The curriculum is only one potential point where positive changes could be made. Indeed, focusing on only the curriculum would provide a threat to Physics in terms of taking the eyes off other things that need to be addressed in parallel.

Physics community operating environment map



Physics community needs map



Ranked requirements table

Customer Requirement or Desired Outcome	Importance: Rank from 0 = Irrelevant 5 = Critical	Satisfaction: Rank from 0 = Not met at all 5 = 100% met	Opportunity Ranking: 10 = Must do through should do, Nice to do, to 0 = Forget it
A high standard physics curriculum in schools that is the floor of what can be delivered and not the ceiling (do not water down the current content), and is delivered by teachers with a tertiary degree in physics and/or mathematics	4.45	1.50	7.39
Maintenance of long term consistency of current funding levels to the physics disciplines	4.43	2.12	6.74
Instantly accessible bridging courses for science teachers that currently have no qualifications in physics	3.98	1.43	6.54
A promotional program to provide the public, teachers, and school children with a clear picture of what physicists and their sub-disciplines do (their professions, activities, responsibilities and achievements)	4.15	1.91	6.39
Mechanisms for kindergarten and primary school teachers to access instructions for experiments that can be easily constructed in any kindergarten and primary school environment with common ingredients to enthuse kindergarten and primary school age children about physics and science	3.92	1.80	6.04
Easily accessible and up to date information for physics graduates on potential employers that have a track record of employing physics graduates	4.00	1.99	6.01
Effective mechanism for funding of cross-disciplinary postgraduate research projects (e.g. physics – engineering, physics – chemistry – engineering, physics – mathematics – computing etc) to foster new ideas and "out of the box" thinking and to sow the seeds for interdisciplinary post-doc research	4.09	2.20	5.97
The physics sub-disciplines, together with the 'mainstream' physics disciplines to develop a united professional image that promotes the importance and impact of both fundamental and applied physics, and employment opportunities and career paths within all sub-discipline groups, to the community	3.85	1.75	5.95
Active promotion of Australian physics research to national and international industry and businesses as a viable alternative to overseas research organizations that are currently used by industry to solve their fundamental and applied research problems	3.99	2.04	5.94
Increased number of longer term research fellowships (six years plus) to retain high calibre early career women in the profession during their child bearing years	3.72	1.51	5.94
Development of interdisciplinary funding models between NH&MRC, ARC, industry funding agencies and research organizations, to foster research that is currently difficult to access funding for, as it does not fit with current funding agency funding rules	3.78	1.64	5.91
A "career description" for typical physics career paths to ensure that school children, their parents and graduates have a clear picture of some of the physics career possibilities to help in their career decision making process	3.82	1.73	5.91
Transparent and equitable metrics and reward systems that measure and reward excellence at all stages of the innovation continuum from fundamental research, applied research, teaching, entrepreneurial activity to working in industry research in order to capture and retain people with the highest skill levels in each of these areas	3.98	2.13	5.83
Equitable balance of work load, teaching and contact hours for male and female physics staff at all levels	3.99	2.34	5.64
Professors and senior academics to become positive role models and promote a balanced and more positive view of other physics related career options in addition to straight research careers (e.g. school teaching, business, government, industry)	3.79	2.12	5.46

Collaboration between universities in the same location (e.g. capital cities and close by regional centres) to fill gaps in teaching and increase the depth and breadth of undergraduate education and honours degrees at the second and third tier universities	3.57	1.71	5.44
Mechanisms for facilitating re-entry of high calibre researchers out of industry careers into academic careers, to re-invigorate physics sub-disciplines that are currently in decline due to the loss of top post graduates and post-docs into highly paid industry positions	3.66	1.89	5.44
Funding programs for early and mid-career level researchers that cannot be accessed by senior career researchers	3.85	2.33	5.37
Evaluation of the effectiveness of university and other research organisation based outreach programs that aim to increase the intake of first year physics students in all universities	3.69	2.05	5.34
Mechanisms that demonstrate that the Physics community is becoming inclusive of the sub-disciplines already split off into their own communities (e.g. geophysics and medical physics), the newly defined sub-disciplines (e.g. econophysics, neurophysics, psychophysics etc.) and the more applied sub-disciplines (e.g. photonics and optics), to avoid inward focus and foster cross-sub-discipline research	3.78	2.22	5.34
Promotional program to continuously promote physics as the springboard to vocational applications and careers	3.53	1.79	5.26
Elimination of penalties in career progression for researchers working on applied physics research compared with fundamental research	3.81	2.39	5.23
Increase the depth and breadth of education of physics graduates	3.80	2.42	5.19
Effective and equitable mentoring schemes in Physics departments (research organizations undertaking physics research) including open door policies so that postgraduates and students can be more effectively mentored and are able to interact more easily with researchers (at all levels) in their organisations	3.95	2.71	5.19
University guidelines that make physics and advanced mathematics compulsory prerequisites for studying physics at university, regardless of tertiary entry score	3.56	2.00	5.12
More hands-on experimentation experience opportunities for undergraduates whilst maintaining a very high standard of fundamental physics training	3.90	2.71	5.10
Develop budget models that allow post-docs to develop closer relationships with industry to attract national and international research funding for fundamental and applied research and improve their income security	3.54	2.02	5.06
Reassessment of the physics higher education courses across all universities so that a complete high quality physics education, research education and service teaching program is provided.	3.82	2.63	5.00
Within funding agencies, development of at least one interdisciplinary panel of experts in addition to the current discipline panels	3.41	1.89	4.92
Inclusion of entrepreneurial activity (time in a start-up company regardless of success of failure) or employment in industry research as a positive factor under the 'Research Opportunity and Performance Evidence (ROPE)' guidelines of funding agencies, HIRD and government research organisations	3.37	1.86	4.88
Develop models for effective collaboration between national and international industry companies and Australian research organisations	3.36	2.10	4.61
Systematic evaluation of commercialisation processes of US HIRD organisations that have a high success rate in commercialization to improve the effectiveness of the commercialisation processes of Australian physics departments	3.00	1.67	4.34
Co-location of fundamental and applied physics research groups working in the same research area	3.37	2.48	4.26
Mandatory undergraduate practical work experience in industry or businesses that employ physicists	2.75	1.33	4.17
Increase of PhD course duration from 3.5 to 4 years	3.02	1.94	4.10

Equity initiatives in each physics department to report and compare the ranking of each physics department according to equity	2.87	2.13	3.62
Develop mutually agreed Key Performance Indicators (KPIs) for industry/business and research organization interaction success	2.68	1.81	3.55
Enforcement of ROPE guidelines in funding schemes and at research organizations when selecting employment candidates	2.95	2.51	3.40
Consolidation of the research activities within smaller universities so that they focus on their current research strengths and relinquish other non-strength research areas to other universities	2.86	2.56	3.17

Table 74 Ranked list of all requirements by opportunity score

(Opportunity scores above the arbitrary cut-off score of 5.34 are shaded yellow).

Separate ranked requirements tables are provided in 11.3.4, under each of the main needs areas.

Appendix 10 ARC funding spreadsheets

Notes on the Data

- In Australia, up until 2008, RFCD (Research Fields, Courses and Disciplines) classification was used to classify research fields. In 2008 RFCD Codes were superseded by Fields of Research (FOR) classifications. Both classifications are hierarchical structures with 3 levels, the top level represented by 2-digit codes, the middle level by 4-digit codes, and the bottom level by 6-digit codes. Research applicants are invited to classify their proposals by 6-digit RFCD/FOR codes and to indicate the proportion of the research content attributable to each of those codes. The ARC rolls up the 6-digit codes to 4-digits as the Primary classification code based on the combined proportions of the 6-digit RFCD/FOR codes.
- The 4-Digit Primary classification codes used to identify research in the area of physics are shown in the 'Physics Codes' tab.
- All schemes for funding commencing in 2011 were classified using FOR codes. For funding commencing in 2010, Discovery Projects was the only scheme still using the RFCD classifications. For funding commencing in 2009 and earlier all schemes were classified using RFCD codes.
- Areas of grey in each of the scheme related tables indicate where schemes had either not yet commenced or where schemes had finished.
- Tables 1 to 5, which relate only to successful projects, use commencement years to display trends over time. Tables 6 to 8, which relate to proposals received and success rates, use submit years to display trends over time.
- Commencement year 2011 does not include the following scheme rounds which are yet to be finalised: Australian Laureate Fellowships; Future Fellowships; and Linkage Projects (Round 2).
- The information shown below is limited to that which was current at the time research proposals were approved for funding and accordingly excludes any post-award variations that may subsequently have been approved. Actual amounts paid to Administering Organisations against approved research projects will vary from the original approvals shown here due to indexation of payments and other post-award funding variations.
- Funding does not include the 4th year extension amounts for the Australian Postgraduate Award (Industry) in Linkage Projects.
- Data does not include co-funded Centres, some projects funded under the Special Research Initiatives scheme and projects funded under the Linkage Learned Academies Special Projects scheme.
- Primary RFCD / FOR Codes used to identify projects in the area of physics.

Primary RFCD / FOR Codes used to identify projects in the area of physics

Classification Type	Classification Code	Classification Code Description
FOR08	0105	MATHEMATICAL PHYSICS
FOR08	0201	ASTRONOMICAL AND SPACE SCIENCES
FOR08	0202	ATOMIC, MOLECULAR, NUCLEAR, PARTICLE AND PLASMA PHYSICS
FOR08	0203	CLASSICAL PHYSICS
FOR08	0204	CONDENSED MATTER PHYSICS
FOR08	0205	OPTICAL PHYSICS
FOR08	0206	QUANTUM PHYSICS
FOR08	0299	OTHER PHYSICAL SCIENCES
FOR08	0404	GEOPHYSICS
RFCD98	2401	ASTRONOMICAL SCIENCES
RFCD98	2402	THEORETICAL AND CONDENSED MATTER PHYSICS
RFCD98	2403	ATOMIC AND MOLECULAR PHYSICS; NUCLEAR AND PARTICLE PHYSICS; PLASMA PHYSICS
RFCD98	2404	OPTICAL PHYSICS
RFCD98	2405	CLASSICAL PHYSICS
RFCD98	2499	OTHER PHYSICAL SCIENCES
RFCD98	2602	GEOPHYSICS

Table 1 - Number of ARC projects funded in the area of physics for commencement years 2002 to 2011 by primary classification code and gender of lea

Primary Classification	Primary Classification Description	Gender of lead investigator	Commencement Year							
			2002	2003	2004	2005	2006	2007	2008	2009
2401 (RFCD98)	ASTRONOMICAL SCIENCES	Female	1	2	3	1	2	2	3	
		Male	18	30	16	22	14	15	26	20
		Total	**19**	**32**	**19**	**23**	**16**	**17**	**29**	**20**
2402 (RFCD98)	THEORETICAL AND CONDENSED MATTER PHYSICS	Female	6	3	5	2	1	2	4	3
		Male	26	30	22	21	20	23	23	21
		Total	**32**	**33**	**27**	**23**	**21**	**25**	**27**	**24**
2403 (RFCD98)	ATOMIC AND MOLECULAR PHYSICS; NUCLEAR AND PARTICLE PHYSICS; PLASMA PHYSICS	Female	1	2	3	1	3		1	2
		Male	16	15	17	8	15	12	17	12
		Total	**17**	**17**	**20**	**9**	**18**	**12**	**18**	**14**
2404 (RFCD98)	OPTICAL PHYSICS	Female	2	4	2	3	3	1	5	1
		Male	15	19	19	12	19	17	20	20
		Total	**17**	**23**	**21**	**15**	**22**	**18**	**25**	**21**
2405 (RFCD98)	CLASSICAL PHYSICS	Female				1	1	1		
		Male	2	4	2	3	3		1	3
		Total	**2**	**4**	**2**	**4**	**4**	**1**	**1**	**3**
2499 (RFCD98)	OTHER PHYSICAL SCIENCES	Female	2	3	3	4	4	2	2	3
		Male	8	10	14	9	10	10	13	6
		Total	**10**	**13**	**17**	**13**	**14**	**12**	**15**	**9**
2602 (RFCD98)	GEOPHYSICS	Female								4
		Male	6	7	9	2	6	6	3	2
		Total	**6**	**7**	**9**	**2**	**6**	**6**	**3**	**6**
0105 (FOR08)	MATHEMATICAL PHYSICS	Female								
		Male								
		Total								
0201 (FOR08)	ASTRONOMICAL AND SPACE SCIENCES	Female								
		Male								
		Total								
0202 (FOR08)	ATOMIC, MOLECULAR, NUCLEAR, PARTICLE AND PLASMA PHYSICS	Female								
		Male								
		Total								
0203 (FOR08)	CLASSICAL PHYSICS	Female								
		Male								
		Total								
0204 (FOR08)	CONDENSED MATTER PHYSICS	Female								
		Male								
		Total								
0205 (FOR08)	OPTICAL PHYSICS	Female								
		Male								
		Total								
0206 (FOR08)	QUANTUM PHYSICS	Female								
		Male								
		Total								
0299 (FOR08)	OTHER PHYSICAL SCIENCES	Female								
		Male								
		Total								

Table 2 - Funding for ARC projects in the area of physics for commencement years 2002 to 2011 by primary classification code and gender of lead inves

Primary Classification	Primary Classification Description	Gender of lead investigator	Commencement Year 2002	2003	2004	2005	2006	2007	2008	2009
2401 (RFCD98)	ASTRONOMICAL SCIENCES	Female	$1,355,000	$480,036	$1,630,000	$111,380	$698,680	$1,197,465	$1,823,400	
		Male	$9,109,384	$11,725,256	$6,473,336	$11,055,831	$7,992,525	$6,166,849	$9,973,451	$13,005,488
		Total	**$10,464,384**	**$12,205,292**	**$8,103,336**	**$11,167,211**	**$8,691,205**	**$7,364,314**	**$11,796,851**	**$13,005,488**
2402 (RFCD98)	THEORETICAL AND CONDENSED MATTER PHYSICS	Female	$2,532,934	$1,840,370	$3,850,829	$229,100	$890,000	$813,070	$3,016,548	$1,439,000
		Male	$6,346,858	$24,827,773	$8,675,154	$5,300,912	$6,357,660	$12,103,226	$10,163,356	$7,638,200
		Total	**$8,879,792**	**$26,668,143**	**$12,525,983**	**$5,530,012**	**$7,247,660**	**$12,916,296**	**$13,179,904**	**$9,077,200**
2403 (RFCD98)	ATOMIC AND MOLECULAR PHYSICS; NUCLEAR AND PARTICLE PHYSICS; PLASMA PHYSICS	Female	$45,343	$641,070	$455,000	$225,000	$924,000		$795,000	$900,570
		Male	$5,786,910	$14,454,640	$6,246,946	$10,321,693	$4,298,500	$8,654,140	$7,302,368	$7,570,847
		Total	**$5,832,253**	**$15,095,710**	**$6,701,946**	**$10,546,693**	**$5,222,500**	**$8,654,140**	**$8,097,368**	**$8,471,417**
2404 (RFCD98)	OPTICAL PHYSICS	Female	$413,118	$2,033,680	$627,886	$451,848	$706,790	$315,000	$2,797,730	$238,182
		Male	$7,571,183	$8,915,435	$6,878,744	$7,588,450	$7,245,054	$7,535,096	$7,634,730	$8,637,400
		Total	**$7,984,301**	**$10,949,115**	**$7,506,630**	**$8,040,298**	**$7,951,844**	**$7,850,096**	**$10,432,460**	**$8,875,582**
2405 (RFCD98)	CLASSICAL PHYSICS	Female				$220,000	$365,000	$1,255,000		
		Male	$425,000	$1,808,774	$590,000	$1,322,212	$735,385		$360,000	$1,245,000
		Total	**$425,000**	**$1,808,774**	**$590,000**	**$1,542,212**	**$1,100,385**	**$1,255,000**	**$360,000**	**$1,245,000**
2499 (RFCD98)	OTHER PHYSICAL SCIENCES	Female	$536,000	$800,066	$1,053,592	$1,092,000	$1,987,000	$429,995	$1,050,000	$1,504,000
		Male	$3,446,500	$2,088,334	$6,098,695	$10,984,665	$4,972,890	$5,497,900	$4,485,652	$3,546,000
		Total	**$3,982,500**	**$2,888,400**	**$7,152,287**	**$12,076,665**	**$6,959,890**	**$5,927,895**	**$5,535,652**	**$5,050,000**
2602 (RFCD98)	GEOPHYSICS	Female								$1,553,000
		Male	$746,755	$1,223,198	$1,749,468	$524,000	$2,252,000	$1,685,757	$1,025,999	$810,000
		Total	**$746,755**	**$1,223,198**	**$1,749,468**	**$524,000**	**$2,252,000**	**$1,685,757**	**$1,025,999**	**$2,363,000**
0105 (FOR08)	MATHEMATICAL PHYSICS	Female								
		Male								
		Total								
0201 (FOR08)	ASTRONOMICAL AND SPACE SCIENCES	Female								
		Male								
		Total								
0202 (FOR08)	ATOMIC, MOLECULAR, NUCLEAR, PARTICLE AND PLASMA PHYSICS	Female								
		Male								
		Total								
0203 (FOR08)	CLASSICAL PHYSICS	Female								
		Male								
		Total								
0204 (FOR08)	CONDENSED MATTER PHYSICS	Female								
		Male								
		Total								
0205 (FOR08)	OPTICAL PHYSICS	Female								
		Male								
		Total								
0206 (FOR08)	QUANTUM PHYSICS	Female								
		Male								
		Total								
0299 (FOR08)	OTHER PHYSICAL SCIENCES	Female								
		Male								
		Total								
0404 (FOR08)	GEOPHYSICS	Female								

Table 3 - **Number of ARC projects funded in the area of physics for commencement years 2002 to 2011 by scheme and gender of lead investigator**

Scheme	Gender of lead investigator	Commencement Year 2002	2003	2004	2005	2006	2007	2008	2009	2010
Australian Laureate Fellowships	Female									
	Male								2	1
	Total								**2**	**1**
Centres of Excellence	Female									
	Male		2		2					
	Total		**2**		**2**					
Discovery Projects	Female	4	7	9	8	12	3	5	8	7
	Male	57	70	59	53	56	49	65	46	59
	Total	**61**	**77**	**68**	**61**	**68**	**52**	**70**	**54**	**66**
Federation Fellowships	Female	1	1					2		
	Male	4	4	4	3	2	5	2		
	Total	**5**	**5**	**4**	**3**	**2**	**5**	**4**		
Future Fellowships	Female									2
	Male								14	27
	Total								**14**	**29**
Linkage Infrastructure, Equipment and Facilities	Female	2	2	3		1	1	4	2	1
	Male	14	10	7	6	11	14	12	8	7
	Total	**16**	**12**	**10**	**6**	**12**	**15**	**16**	**10**	**8**
Linkage International	Female	2		3	2	1		1		
	Male	10	10	20	4	13	9	15	8	
	Total	**12**	**10**	**23**	**6**	**14**	**9**	**16**	**8**	
Linkage Projects	Female	3	4	1	1		4	3	3	1
	Male	6	15	8	6	5	6	9	6	6
	Total	**9**	**19**	**9**	**7**	**5**	**10**	**12**	**9**	**7**
Research Networks	Female									
	Male			1						
	Total			**1**						
Special Research Initiatives	Female				1					
	Male		4		3					
	Total		**4**		**4**					
Super Science Fellowships	Female									2
	Male									9
	Total									**11**
Total - All Schemes	Female	12	14	16	12	14	8	15	13	13
	Male	91	115	99	77	87	83	103	84	109
	Total	**103**	**129**	**115**	**89**	**101**	**91**	**118**	**97**	**122**

Table 4 - Funding for ARC projects in the area of physics for commencement years 2002 to 2011 by scheme and gender of lead investigator

Scheme	Gender of lead investigator	Commencement Year 2002	2003	2004	2005	2006	2007	2008	2009	2010
Australian Laureate Fellowships	Female									
	Male								$6,085,393	$2,784,765
	Total								**$6,085,393**	**$2,784,765**
Centres of Excellence	Female									
	Male		$24,950,000		$16,000,000					
	Total		**$24,950,000**		**$16,000,000**					
Discovery Projects	Female	$2,385,529	$2,924,106	$3,924,000	$2,030,248	$4,427,680	$1,516,535	$1,767,000	$3,736,752	$2,864,594
	Male	$20,663,708	$26,706,460	$21,754,921	$20,375,156	$21,815,224	$23,387,948	$28,110,802	$18,890,182	$25,138,670
	Total	**$23,049,237**	**$29,630,566**	**$25,678,921**	**$22,405,404**	**$26,242,904**	**$24,904,483**	**$29,877,802**	**$22,626,934**	**$28,003,264**
Federation Fellowships	Female	$1,417,500	$1,450,370					$3,277,460		
	Male	$5,670,000	$5,801,480	$6,078,840	$5,453,875	$3,162,220	$8,795,175	$2,951,095		
	Total	**$7,087,500**	**$7,251,850**	**$6,078,840**	**$5,453,875**	**$3,162,220**	**$8,795,175**	**$6,228,555**		
Future Fellowships	Female									$1,171,341
	Male								$10,531,200	$18,832,073
	Total								**$10,531,200**	**$20,003,414**
Linkage Infrastructure, Equipment and Facilities	Female	$672,000	$550,000	$2,887,715		$1,047,000	$494,000	$3,230,000	$1,350,000	$400,000
	Male	$5,814,255	$5,201,121	$4,101,025	$2,980,311	$6,045,050	$6,911,000	$5,726,224	$3,987,000	$2,200,000
	Total	**$6,486,255**	**$5,751,121**	**$6,988,740**	**$2,980,311**	**$7,092,050**	**$7,405,000**	**$8,956,224**	**$5,337,000**	**$2,600,000**
Linkage International	Female	$76,388		$161,600	$37,700	$96,790		$50,400		
	Male	$309,171	$270,120	$1,130,299	$240,480	$637,070	$380,947	$823,435	$577,160	
	Total	**$385,559**	**$270,120**	**$1,291,899**	**$278,180**	**$733,860**	**$380,947**	**$873,835**	**$577,160**	
Linkage Projects	Female	$330,978	$870,746	$643,992	$150,000		$1,999,995	$1,157,818	$548,000	$600,000
	Male	$975,456	$2,024,229	$2,147,258	$1,705,789	$2,194,450	$2,167,898	$3,334,000	$2,382,000	$2,041,773
	Total	**$1,306,434**	**$2,894,975**	**$2,791,250**	**$1,855,789**	**$2,194,450**	**$4,167,893**	**$4,491,818**	**$2,930,000**	**$2,641,773**
Research Networks	Female									
	Male			$1,500,000						
	Total			**$1,500,000**						
Special Research Initiatives	Female				$111,380					
	Male		$90,000		$342,152					
	Total		**$90,000**		**$453,532**					
Super Science Fellowships	Female									$1,670,400
	Male									$4,176,000
	Total									**$5,846,400**
Total - All Schemes	Female	$4,882,395	$5,795,222	$7,617,307	$2,329,328	$5,571,470	$4,010,530	$9,482,678	$5,634,752	$6,706,335
	Male	$33,432,590	$65,043,410	$36,712,343	$47,097,763	$33,854,014	$41,642,968	$40,945,556	$42,452,935	$55,173,281
	Total	**$38,314,985**	**$70,838,632**	**$44,329,650**	**$49,427,091**	**$39,425,484**	**$45,653,498**	**$50,428,234**	**$48,087,687**	**$61,879,616**

Table 5 - Number of ARC fellowships funded in the area of physics for commencement years 2002 to 2011 by fellowship type and gender of fellow

Fellowship type	Gender of Fellow	Commencement Year									
		2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Australian Laureate Fellowship	Male								2	1	
	Total								**2**	**1**	
Australian Postdoctoral Fellowship	Female	1	3	3	4	3		2	3	1	2
	Male	8	13	6	6	15	10	13	9	10	7
	Total	**9**	**16**	**9**	**10**	**18**	**10**	**15**	**12**	**11**	**9**
Australian Postdoctoral Fellowship (Industry)	Female		1				1	1			
	Male	1	2	2				2		1	1
	Total	**1**	**3**	**2**			**1**	**3**		**1**	**1**
Australian Professorial Fellowship	Female			1							
	Male	2	6	2	1	3	4	4		3	4
	Total	**2**	**6**	**3**	**1**	**3**	**4**	**4**		**3**	**4**
Australian Research Fellowship / Queen Elizabeth II Fellowship	Female	2	1				3		3	2	
	Male	1	4	6	3	3	6	8	5	9	2
	Total	**3**	**5**	**6**	**3**	**3**	**9**	**8**	**8**	**11**	**2**
Federation Fellowship	Female	1	1					2			
	Male	4	4	4	3	2	5	2			
	Total	**5**	**5**	**4**	**3**	**2**	**5**	**4**			
Future Fellowship	Female									2	
	Male								14	27	
	Total								**14**	**29**	
Linkage International Fellowship	Female							2			
	Male					5	1	3	8		
	Not specified	1		5							
	Total	**1**		**5**		**5**	**1**	**5**	**8**		
Super Science Fellowship	Not specified									21	19
	Total									**21**	**19**
Total - All fellowships	Female	4	6	4	4	3	4	7	6	5	2
	Male	16	29	20	13	28	26	32	38	51	14
	Not specified	1	0	5	0	0	0	0	0	21	19
	Total	**21**	**35**	**29**	**17**	**31**	**30**	**39**	**44**	**77**	**35**

Table 6 - Number of ARC proposals submitted in the area of physics for submit years 2001 to 2010 by scheme and gender of lead investigator

Scheme	Gender of lead investigator	Submit Year									
		2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Australian Laureate Fellowships	Female								1		
	Male								23	14	
	Total								**24**	**14**	
Centres of Excellence	Female		2		1						1
	Male		5		9						4
	Total		**7**		**10**						**5**
Discovery Projects	Female	16	29	28	31	39	30	37	41	43	34
	Male	206	238	197	187	222	241	263	240	242	272
	Total	**222**	**267**	**225**	**218**	**261**	**271**	**300**	**281**	**285**	**306**
Federation Fellowships	Female		2		2	1	1	3			
	Male	25	27	25	33	20	15	18			
	Total	**25**	**29**	**25**	**35**	**21**	**16**	**21**			
Future Fellowships	Female								7		10
	Male								67		60
	Total								**74**		**70**
Linkage Infrastructure, Equipment and Facilities	Female	4	2	4	1	3	2	5	4	4	3
	Male	17	16	14	18	17	23	15	15	15	16
	Total	**21**	**18**	**18**	**19**	**20**	**25**	**20**	**19**	**19**	**19**
Linkage International	Female	1	2	3	2	2	4	1	1		
	Male	10	15	25	10	30	34	26	14		
	Total	**11**	**17**	**28**	**12**	**32**	**38**	**27**	**15**		
Linkage Projects	Female	5	6	2	2		5	4	5	1	
	Male	10	26	15	8	13	17	19	16	13	8
	Total	**15**	**32**	**17**	**10**	**13**	**22**	**23**	**21**	**14**	**8**
Research Networks	Female				1						
	Male				5						
	Total				**6**						
Special Research Initiatives	Female			1	1						
	Male			14	3						
	Total			**15**	**4**						
Super Science Fellowships	Female									6	
	Male									28	
	Total									**34**	
Total - all schemes	Female	26	43	38	41	45	42	50	59	54	48
	Male	268	327	290	273	302	330	341	375	312	360
	Total	**294**	**370**	**328**	**314**	**347**	**372**	**391**	**434**	**366**	**408**

Table 7 - Number of ARC projects funded in the area of physics for submit years 2001 to 2010 by scheme and gender of lead investigator

Scheme	Gender of lead investigator	Submit Year 2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Australian Laureate Fellowships	Female										
	Male								2	1	
	Total								**2**	**1**	
Centres of Excellence	Female										1
	Male		2		2						4
	Total		**2**		**2**						**5**
Discovery Projects	Female	4	7	9	8	12	3	5	8	7	8
	Male	57	70	59	53	56	49	65	46	59	62
	Total	**61**	**77**	**68**	**61**	**68**	**52**	**70**	**54**	**66**	**70**
Federation Fellowships	Female		2					2			
	Male	3	5	4	3	2	5	2			
	Total	**3**	**7**	**4**	**3**	**2**	**5**	**4**			
Future Fellowships	Female										2
	Male								14		27
	Total								**14**		**29**
Linkage Infrastructure, Equipment and Facilities	Female	2	2	3		1	1	4	2	1	2
	Male	14	10	7	6	11	14	12	8	7	9
	Total	**16**	**12**	**10**	**6**	**12**	**15**	**16**	**10**	**8**	**11**
Linkage International	Female	1	1	3	2	1		1			
	Male	7	15	15	8	10	11	15	8		
	Total	**8**	**16**	**18**	**10**	**11**	**11**	**16**	**8**		
Linkage Projects	Female	3	4	1	1		4	3	3	1	
	Male	6	15	8	6	5	6	9	6	6	7
	Total	**9**	**19**	**9**	**7**	**5**	**10**	**12**	**9**	**7**	**7**
Research Networks	Female										
	Male				1						
	Total				**1**						
Special Research Initiatives	Female				1						
	Male			4	3						
	Total			**4**	**4**						
Super Science Fellowships	Female									3	
	Male									17	
	Total									**20**	
Total - all schemes	Female	10	16	16	12	14	8	15	13	12	13
	Male	87	117	97	82	84	85	103	84	90	109
	Total	**97**	**133**	**113**	**94**	**98**	**93**	**118**	**97**	**102**	**122**

Table 8 - Success rates for proposals in the area of physics for submit years 2001 to 2010 by scheme and gender of lead

Scheme	Gender of lead investigator	Submit Year									
		2001	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Australian Laureate Fellowships	Female								0.0%		
	Male								8.7%	7.1%	
	Total								**8.3%**	**7.1%**	
Centres of Excellence	Female		0.0%		0.0%						100.0%
	Male		40.0%		22.2%						100.0%
	Total		**28.6%**		**20.0%**						**100.0%**
Discovery Projects	Female	25.0%	24.1%	32.1%	25.8%	30.8%	10.0%	13.5%	19.5%	16.3%	23.5%
	Male	27.7%	29.4%	29.9%	28.3%	25.2%	20.3%	24.7%	19.2%	24.4%	22.8%
	Total	**27.5%**	**28.8%**	**30.2%**	**28.0%**	**26.1%**	**19.2%**	**23.3%**	**19.2%**	**23.2%**	**22.9%**
Federation Fellowships	Female		100.0%		0.0%	0.0%	0.0%	66.7%			
	Male	12.0%	18.5%	16.0%	9.1%	10.0%	33.3%	11.1%			
	Total	**12.0%**	**24.1%**	**16.0%**	**8.6%**	**9.5%**	**31.3%**	**19.0%**			
Future Fellowships	Female								0.0%		20.0%
	Male								20.9%		45.0%
	Total								**18.9%**		**41.4%**
Linkage Infrastructure, Equipment and Facilities	Female	50.0%	100.0%	75.0%	0.0%	33.3%	50.0%	80.0%	50.0%	25.0%	66.7%
	Male	82.4%	62.5%	50.0%	33.3%	64.7%	60.9%	80.0%	53.3%	46.7%	56.3%
	Total	**76.2%**	**66.7%**	**55.6%**	**31.6%**	**60.0%**	**60.0%**	**80.0%**	**52.6%**	**42.1%**	**57.9%**
Linkage International	Female	100.0%	50.0%	100.0%	100.0%	50.0%	0.0%	100.0%	0.0%		
	Male	70.0%	100.0%	60.0%	80.0%	33.3%	32.4%	57.7%	57.1%		
	Total	**72.7%**	**94.1%**	**64.3%**	**83.3%**	**34.4%**	**28.9%**	**59.3%**	**53.3%**		
Linkage Projects	Female	60.0%	66.7%	50.0%	50.0%		80.0%	75.0%	60.0%	100.0%	
	Male	60.0%	57.7%	53.3%	75.0%	38.5%	35.3%	47.4%	37.5%	46.2%	87.5%
	Total	**60.0%**	**59.4%**	**52.9%**	**70.0%**	**38.5%**	**45.5%**	**52.2%**	**42.9%**	**50.0%**	**87.5%**
Research Networks	Female				0.0%						
	Male				20.0%						
	Total				**16.7%**						
Special Research Initiatives	Female			0.0%	100.0%						
	Male			28.6%	100.0%						
	Total			**26.7%**	**100.0%**						
Super Science Fellowships	Female									50.0%	
	Male									60.7%	
	Total									**58.8%**	
Total - all schemes	Female	38.5%	37.2%	42.1%	29.3%	31.1%	19.0%	30.0%	22.0%	22.2%	27.1%
	Male	32.5%	35.8%	33.4%	30.0%	27.8%	25.8%	30.2%	22.4%	28.8%	30.3%
	Total	**33.0%**	**35.9%**	**34.5%**	**29.9%**	**28.2%**	**25.0%**	**30.2%**	**22.4%**	**27.9%**	**29.9%**

Appendix 11 Higher education statistics spreadsheets

	Introduction
Intro	Field of Education and Discipline Group Codes
	Student Load 2002 - 2009
Table 1	Teaching to students enrolled in courses at all course levels in All Fields of Education, by Discipline Group
Table 2	Teaching to students enrolled in courses at all course levels in Natural & Physical Sciences, by Discipline Group
Table 3	Teaching to students enrolled in PhD courses in Natural and Physical Sciences, by Discipline Group and Gender
Table 4	Teaching to students enrolled in PhD courses in Natural and Physical Sciences, by Discipline Group and Citizenship Status
Table 5	Teaching to students enrolled in all courses at all course levels in Natural and Physical Sciences, by Discipline Group
	Course Completions 2002 - 2009
Table 6	Students Enrolled in Courses (all levels) in the Natural and Physical Sciences
Table 7	Natural and Physical Sciences Students in MPS as Primary or Secondary Course
Table 8	Course Completions 2002 - 2009: Natural and Physical Sciences Students - All Course Levels by Citizenship Status
Table 9	Course Completions 2002 - 2009: Natural and Physical Sciences Students - PhDs by Citizenship Status
Table 10	Course Completions 2002 - 2009: Natural and Physical Sciences Students - All Course Levels by Gender
Table 11	Course Completions 2002 - 2009: Natural and Physical Sciences Students - PhDs by Gender
	Enrolments 2002 - 2009
Table 12	PhD Student Enrolments: All Fields of Education
Table 13	PhD Student Enrolments: Natural and Physical Sciences

Fields of Education and Discipline Group Codes: Natural and Physical Sciences #

01	**Natural and Physical Sciences**
010100	Mathematical Sciences
010101	Mathematics
010103	Statistics
010199	Mathematical Sciences not elsewhere classified
010300	Physics and Astronomy
010301	Physics
010303	Astronomy
010500	Chemical Sciences
010501	Organic Chemistry
010503	Inorganic Chemistry
010599	Chemical Sciences not elsewhere classified
010700	Earth Sciences
010701	Atmospheric Sciences
010703	Geology
010705	Geophysics
010707	Geochemistry
010709	Soil Science
010711	Hydrology
010713	Oceanography
010799	Earth Sciences not elsewhere classified
010900	Biological Sciences
010901	Biochemistry and Cell Biology
010903	Botany
010905	Ecology and Evolution
010907	Marine Science
010909	Genetics
010911	Microbiology
010913	Human Biology
010915	Zoology
010999	Biological Sciences not elsewhere classified
019900	Other Natural and Physical Sciences
019901	Medical Science
019903	Forensic Science
019905	Food Science and Biotechnology
019907	Pharmacology
019909	Laboratory Technology
019999	Natural and Physical Sciences not elsewhere classified

These are the formal FoE / GD Codes. There is one additional 'informal' code (010000) used by universities that have not coded courses and subjects more specifically than 'Natural & Physical Sciences'. In these statistics, entities coded thus have been

Table 1										
Student Load 2002 - 2009	**Teaching to students enrolled in courses at all course levels in All Fields of Education, by Discipline Group**									
Discipline Group	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**Growth - No.**	**Growth - %**
No.										
Mathematical Sciences	20519	20906	21127	20326	20971	22099	22968	26216	5696	27.8%
Physical Sciences										
Physics & Astronomy	1146	1105	531	294	122	131	128	133	-1013	-88.4%
Physics	3580	3592	4115	4099	4449	4653	4657	5170	1590	44.4%
Astronomy	267	286	323	300	302	291	309	354	86	32.3%
Sub-total	4994	4984	4970	4693	4873	5075	5094	5657	663	13.3%
Chemical Sciences	7621	7828	8060	8069	8277	8614	8606	9332	1712	22.5%
Earth Sciences	3897	3864	3661	3432	3508	3650	3919	4746	849	21.8%
Biological Sciences	30512	31434	32030	32645	33970	35584	35972	38434	7922	26.0%
Other Sciences	6192	6580	7560	7284	7868	8516	8890	10225	4032	65.1%
All Natural & Physical Sciences	**73735**	**75597**	**77407**	**76449**	**79467**	**83538**	**85449**	**94610**	**20874**	**28.3%**
Per Cent										
Mathematical Sciences	27.8%	27.7%	27.3%	26.6%	26.4%	26.5%	26.9%	27.7%		
Physical Sciences										
Physics & Astronomy	1.6%	1.5%	0.7%	0.4%	0.2%	0.2%	0.1%	0.1%		
Physics	4.9%	4.8%	5.3%	5.4%	5.6%	5.6%	5.5%	5.5%		
Astronomy	0.4%	0.4%	0.4%	0.4%	0.4%	0.3%	0.4%	0.4%		
Sub-total	6.8%	6.6%	6.4%	6.1%	6.1%	6.1%	6.0%	6.0%		
Chemical Sciences	10.3%	10.4%	10.4%	10.6%	10.4%	10.3%	10.1%	9.9%		
Earth Sciences	5.3%	5.1%	4.7%	4.5%	4.4%	4.4%	4.6%	5.0%		
Biological Sciences	41.4%	41.6%	41.4%	42.7%	42.7%	42.6%	42.1%	40.6%		
Other Sciences	8.4%	8.7%	9.8%	9.5%	9.9%	10.2%	10.4%	10.8%		
All Natural & Physical Sciences	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**		
Source: DEEWR (DETYA/DEST) Aggregated student load files ULAGyyyy for years 2002 - 2009										
Note: This table shows all teaching in 01 Natural and Physical Sciences disciplines to students in all university courses at all course levels.										

Table 2										
Student Load 2002 - 2009	**Teaching to students enrolled in courses at all course levels in Natural & Physical Sciences, by Discipline Group**									
Discipline Group	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**Growth - No.**	**Growth - %**
No.										
Mathematical Sciences	4988	5175	5269	4034	5133	5100	5272	6067	1079	21.6%
Physical Sciences										
Physics & Astronomy	668	662	299	203	54	52	60	79	-589	-88.2%
Physics	1763	1828	2224	1997	2595	2578	2560	2798	1035	58.7%
Astronomy	211	236	268	258	258	247	258	293	83	39.2%
Sub-total	2641	2727	2790	2458	2907	2877	2878	3170	529	20.0%
Chemical Sciences	5135	5303	5491	4653	5725	5822	5756	6130	995	19.4%
Earth Sciences	2414	2378	2218	1803	2137	2286	2462	2945	530	22.0%
Biological Sciences	16964	17701	18347	16602	19271	19788	19905	20949	3985	23.5%
Other Sciences	3372	3754	4132	3640	4245	4537	4650	5158	1786	53.0%
All Natural & Physical Sciences	**35514**	**37038**	**38247**	**33190**	**39418**	**40410**	**40923**	**44418**	**8904**	**25.1%**
Per Cent										
Mathematical Sciences	14.0%	14.0%	13.8%	12.2%	13.0%	12.6%	12.9%	13.7%		
Physical Sciences										
Physics & Astronomy	1.9%	1.8%	0.8%	0.6%	0.1%	0.1%	0.1%	0.2%		
Physics	5.0%	4.9%	5.8%	6.0%	6.6%	6.4%	6.3%	6.3%		
Astronomy	0.6%	0.6%	0.7%	0.8%	0.7%	0.6%	0.6%	0.7%		
Sub-total	7.4%	7.4%	7.3%	7.4%	7.4%	7.1%	7.0%	7.1%		
Chemical Sciences	14.5%	14.3%	14.4%	14.0%	14.5%	14.4%	14.1%	13.8%		
Earth Sciences	6.8%	6.4%	5.8%	5.4%	5.4%	5.7%	6.0%	6.6%		
Biological Sciences	47.8%	47.8%	48.0%	50.0%	48.9%	49.0%	48.6%	47.2%		
Other Sciences	9.5%	10.1%	10.8%	11.0%	10.8%	11.2%	11.4%	11.6%		
All Natural & Physical Sciences	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**		
Source: DEEWR (DETYA/DEST) Aggregated student load files ULAGyyyy for years 2002 - 2009										
Note: This table shows all teaching in 01 Natural and Physical Sciences disciplines to students in university courses in the Natural & Physical Sciences field of education, at all course levels.										

Table 3										
Student Load 2002 - 2009	**Teaching to students enrolled in PhD courses in Natural and Physical Sciences, by Discipline Group and Gender**									
Discipline Group	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**Growth - No.**	**Growth - %**
Female students										
Mathematical Sciences	82	100	110	127	149	146	144	150	68	83.0%
Physical Sciences										
Physics & Astronomy	38	37	22	41	2	4	7	5	-33	-86.4%
Physics	94	92	110	94	113	122	131	143	49	52.6%
Astronomy	9	13	14	14	15	16	16	18	8	90.1%
Sub-total	141	142	147	149	130	142	154	166	25	17.4%
Chemical Sciences	278	318	326	339	372	372	409	446	168	60.4%
Earth Sciences	213	222	201	193	189	203	194	212	-1	-0.6%
Biological Sciences	1192	1289	1405	1603	1666	1708	1713	1763	571	47.9%
Other Sciences	318	324	346	362	390	455	471	460	142	44.6%
Total - Female	2225	2395	2536	2773	2896	3026	3085	3197	973	43.7%
Male students										
Mathematical Sciences	225	240	265	259	262	275	300	323	97	43.1%
Physical Sciences										
Physics & Astronomy	94	88	47	110	8	10	16	21	-73	-77.4%
Physics	263	284	380	360	489	504	520	548	285	108.4%
Astronomy	14	16	35	47	48	46	46	39	25	179.0%
Sub-total	371	388	462	517	545	560	582	608	238	64.0%
Chemical Sciences	386	382	407	421	461	506	535	551	165	42.7%
Earth Sciences	406	409	390	356	322	286	284	293	-114	-27.9%
Biological Sciences	1034	1089	1184	1293	1316	1313	1296	1366	332	32.1%
Other Sciences	309	302	331	311	330	367	339	333	23	7.5%
Total - Male	2733	2809	3039	3157	3236	3307	3336	3474	741	27.1%
All students										
Mathematical Sciences	308	340	374	386	411	421	444	473	165	53.7%
Physical Sciences										
Physics & Astronomy	132	125	70	151	10	14	23	26	-106	-80.0%
Physics	357	376	490	454	602	626	651	692	335	93.7%
Astronomy	23	29	49	61	63	62	62	57	33	143.7%
Sub-total	512	530	609	666	675	702	736	775	262	51.2%
Chemical Sciences	665	700	733	760	833	878	944	998	333	50.1%
Earth Sciences	619	631	592	549	511	489	478	504	-115	-18.5%
Biological Sciences	2226	2378	2589	2896	2982	3021	3009	3129	903	40.6%
Other Sciences	628	625	677	673	720	822	810	793	165	26.3%
Total - All	**4957**	**5204**	**5574**	**5930**	**6132**	**6333**	**6421**	**6671**	**1714**	**34.6%**

Table 3 (cont'd)								
Student Load 2002 - 2009	**Teaching to students enrolled in PhD courses in Natural and Physical Sciences, by Discipline Group and Gender**							
Discipline Group	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
Female % of All								
Mathematical Sciences	26.7%	29.5%	29.3%	32.9%	36.3%	34.7%	32.4%	31.8%
Physical Sciences								
Physics & Astronomy	29.0%	29.7%	32.2%	27.2%	20.0%	28.6%	30.4%	19.7%
Physics	26.3%	24.5%	22.5%	20.7%	18.8%	19.5%	20.1%	20.7%
Astronomy	39.8%	44.9%	28.9%	23.0%	23.8%	25.8%	25.8%	31.0%
Sub-total	27.6%	26.9%	24.1%	22.4%	19.3%	20.2%	20.9%	21.4%
Chemical Sciences	41.9%	45.4%	44.5%	44.6%	44.7%	42.4%	43.3%	44.7%
Earth Sciences	34.4%	35.2%	34.0%	35.2%	37.0%	41.5%	40.6%	42.0%
Biological Sciences	53.5%	54.2%	54.3%	55.4%	55.9%	56.5%	56.9%	56.3%
Other Sciences	50.7%	51.8%	51.1%	53.8%	54.2%	55.4%	58.1%	58.1%
Total - All	**44.9%**	**46.0%**	**45.5%**	**46.8%**	**47.2%**	**47.8%**	**48.0%**	**47.9%**

Table 4										
Student Load 2002 - 2009	**Teaching to students enrolled in PhD courses in Natural and Physical Sciences, by Discipline Group and Citizenship Status**									
Discipline Group	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**Growth - No.**	**Growth - %**
Overseas Students										
Mathematical Sciences	60	69	73	76	97	115	134	171	110	183.5%
Physical Sciences										
Physics & Astronomy	13	21	17	35	2	3	10	11	-2	-16.0%
Physics	59	66	91	96	124	126	147	175	116	196.7%
Astronomy	6	8	23	27	29	27	23	22	17	307.0%
Sub-total	78	96	131	158	155	156	180	208	131	168.5%
Chemical Sciences	101	103	117	142	184	231	268	296	195	193.1%
Earth Sciences	112	113	122	140	145	162	191	221	109	97.3%
Biological Sciences	306	378	421	486	541	611	702	840	533	174.1%
Other Sciences	112	112	123	127	148	177	179	219	107	96.1%
Total - Overseas Students	**769**	**871**	**987**	**1129**	**1270**	**1452**	**1654**	**1955**	**1186**	**154.2%**
Domestic Students										
Mathematical Sciences	247	271	302	310	314	306	310	302	55	22.2%
Physical Sciences										
Physics & Astronomy	119	104	53	116	8	11	13	15	-104	-87.1%
Physics	298	310	399	358	478	500	504	517	219	73.3%
Astronomy	18	21	26	34	34	35	39	34	17	93.1%
Sub-total	435	434	478	508	520	546	556	566	132	30.2%
Chemical Sciences	564	596	616	618	649	647	676	702	138	24.5%
Earth Sciences	507	518	470	507	366	327	287	283	-224	-44.2%
Biological Sciences	1920	2000	2169	2410	2441	2410	2307	2289	370	19.3%
Other Sciences	516	513	554	546	572	645	631	574	58	11.2%
Total - Domestic Students	**4188**	**4333**	**4587**	**4899**	**4862**	**4881**	**4767**	**4716**	**528**	**12.6%**
All Students										
Mathematical Sciences	308	340	374	386	411	421	444	473	165	53.7%
Physical Sciences										
Physics & Astronomy	132	125	70	151	10	14	23	26	-106	-80.0%
Physics	357	376	490	454	602	626	651	692	335	93.7%
Astronomy	23	29	49	61	63	62	62	57	33	143.7%
Sub-total	512	530	609	666	675	702	736	775	262	51.2%
Chemical Sciences	665	700	733	760	833	878	944	998	333	50.1%
Earth Sciences	619	631	592	647	511	489	478	504	-115	-18.5%
Biological Sciences	2226	2378	2589	2896	2982	3021	3009	3129	903	40.6%
Other Sciences	628	625	677	673	720	822	810	793	165	26.3%
Total - All Students	**4957**	**5204**	**5574**	**6028**	**6132**	**6333**	**6421**	**6671**	**1714**	**34.6%**

Table 4 (cont'd)								
Student Load 2002 - 2009	Teaching to students enrolled in PhD courses in Natural and Physical Sciences, by Discipline Group and Citizenship Status							
Discipline Group	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
Overseas % of All								
Mathematical Sciences	19.6%	20.2%	19.4%	19.7%	23.6%	27.3%	30.2%	36.1%
Physical Sciences								
Physics & Astronomy	10.0%	16.7%	24.2%	23.2%	20.0%	21.4%	43.5%	41.8%
Physics	16.5%	17.7%	18.6%	21.1%	20.6%	20.1%	22.6%	25.3%
Astronomy	23.7%	29.2%	47.1%	44.3%	46.0%	43.5%	37.1%	39.5%
Sub-total	15.1%	18.1%	21.5%	23.7%	23.0%	22.2%	24.5%	26.9%
Chemical Sciences	15.2%	14.8%	16.0%	18.7%	22.1%	26.3%	28.4%	29.6%
Earth Sciences	18.1%	17.9%	20.6%	21.6%	28.4%	33.1%	40.0%	43.9%
Biological Sciences	13.8%	15.9%	16.2%	16.8%	18.1%	20.2%	23.3%	26.8%
Other Sciences	17.8%	17.9%	18.2%	18.9%	20.6%	21.5%	22.1%	27.6%
% - All Students	**15.5%**	**16.7%**	**17.7%**	**18.7%**	**20.7%**	**22.9%**	**25.8%**	**29.3%**

Table 5										
Student Load 2002 - 2009	**Teaching to students enrolled in all courses at all course levels in Natural and Physical Sciences, by Discipline Group**									
Discipline Group - No.	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**Growth - No.**	**Growth - %**
Mathematical Sciences	4988	5175	5269	4034	5133	5100	5272	6067	1079	21.6%
Physical Sciences	2641	2727	2790	2458	2907	2877	2878	3170	529	20.0%
Chemical Sciences	5135	5303	5491	4653	5725	5822	5756	6130	995	19.4%
Earth Sciences	2414	2378	2218	1803	2137	2286	2462	2945	530	22.0%
Biological Sciences	16964	17701	18347	16602	19271	19788	19905	20949	3985	23.5%
Other Sciences	3372	3754	4132	3640	4245	4537	4650	5158	1786	53.0%
Total - All Students	**35,514**	**37,038**	**38,247**	**33190**	**39418**	**40410**	**40923**	**44,418**	**8904**	**25.1%**
Discipline Group - %										
Mathematical Sciences	14.0%	14.0%	13.8%	12.2%	13.0%	12.6%	12.9%	13.7%		
Physical Sciences	7.4%	7.4%	7.3%	7.4%	7.4%	7.1%	7.0%	7.1%		
Chemical Sciences	14.5%	14.3%	14.4%	14.0%	14.5%	14.4%	14.1%	13.8%		
Earth Sciences	6.8%	6.4%	5.8%	5.4%	5.4%	5.7%	6.0%	6.6%		
Biological Sciences	47.8%	47.8%	48.0%	50.0%	48.9%	49.0%	48.6%	47.2%		
Other Sciences	9.5%	10.1%	10.8%	11.0%	10.8%	11.2%	11.4%	11.6%		
% - All Students	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**		

Table 6										
Course Completions 2002 - 2009	**Students in Courses (all levels) in the Natural and Physical Sciences**									
	2002	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**Growth - No.**	**Growth - %**
Natural and Physical Sciences Only	13158	13577	14767	15244	15749	16083	16320	16167	3009	22.9%
Combined course completion with:										
Information Technology	21	21	34	49	29	30	33	18	-3	-14.3%
Engineering and Related Technologies	210	274	200	261	265	264	274	252	42	20.0%
Architecture and Building			1	2	4	4	6	5	5	
Agriculture, Environmental and Related Studies				3	2	2	5	2	2	
Health	66	65	92	110	159	157	158	167	101	153.0%
Education	62	79	121	121	128	143	158	127	65	104.8%
Management and Commerce	120	180	226	237	225	199	203	194	74	61.7%
Society and Culture	329	243	212	215	265	222	154	156	-173	-52.6%
Creative Arts	7	4	3	3	1	1	1	5	-2	-28.6%
Sub-total secondary courses	815	866	889	1001	1078	1022	992	926	111	13.6%
Total NPS Course Completers	**13973**	**14443**	**15656**	**16245**	**16827**	**17105**	**17312**	**17093**	**3120**	**22.3%**

Note: This table enumerates all graduates in the Natural and Physical Sciences (NPS) , including those that also graduated with a qualification from another field of education. E.g., the Society and Culture row includes students that graduated at the same time with arts or law degrees. With the exception of the next table, other tables show only graduations where the NPS course was the primary course.

Table 7										
Course Completions 2002 - 2009	**Natural and Physical Sciences Students in NPS as Primary or Secondary Course**									
Field of Education	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**Growth - No.**	**Growth - %**
Mathematical Sciences	682	702	675	666	689	728	717	715	33	4.8%
Physical Sciences										
Physics & Astronomy	79	116	89	67	68	59	35	69	-10	-12.7%
Physics	237	303	272	284	331	312	347	283	46	19.4%
Astronomy	23	43	60	56	58	64	53	59	36	156.5%
Sub-total	339	462	421	407	457	435	435	411	72	21.2%
Chemical Sciences	517	512	572	441	516	522	563	501	-16	-3.1%
Earth Sciences	512	435	523	429	340	330	359	393	-119	-23.2%
Biological Sciences	3803	4088	4281	4200	4155	4067	4258	4146	343	9.0%
Other Natural and Physical Sciences Courses	7305	7378	8295	9101	9592	10001	9988	10001	2696	36.9%
Sub-total	**13158**	**13577**	**14767**	**15244**	**15749**	**16083**	**16320**	**16167**	**3009**	**45.7%**
Sub-total secondary courses	815	866	889	1001	1078	1022	992	926	111	13.6%
Total	**13973**	**14443**	**15656**	**16245**	**16827**	**17105**	**17312**	**17093**	**3120**	**22.3%**

Table 8

Course Completions 2002 - 2009 — **Course Completions 2002 - 2009: Natural and Physical Sciences Students - All Course Levels by Citizenship Status**

Field of Education / Citizenship Status	2002	2003	2004	2005	2006	2007	2008	2009	Growth - No.	Growth - %
Mathematical Sciences										
Overseas	77	90	99	97	97	134	143	153	76	98.7%
Domestic	605	612	576	569	592	594	574	562	-43	-7.1%
Sub-total	682	702	675	666	689	728	717	715	33	4.8%
Overseas % of All	11.3%	12.8%	14.7%	14.6%	14.1%	18.4%	19.9%	21.4%	230.3%	
Physical Sciences										
Overseas	60	85	86	66	100	115	112	136	76	126.7%
Domestic	279	377	335	341	357	320	323	275	-4	-1.4%
Sub-total	339	462	421	407	457	435	435	411	72	21.2%
Overseas % of All	17.7%	18.4%	20.4%	16.2%	21.9%	26.4%	25.7%	33.1%	105.6%	
Chemical Sciences										
Overseas	56	63	59	64	89	85	104	123	67	119.6%
Domestic	461	449	513	377	427	437	459	378	-83	-18.0%
Sub-total	517	512	572	441	516	522	563	501	-16	-3.1%
Overseas % of All	10.8%	12.3%	10.3%	14.5%	17.2%	16.3%	18.5%	24.6%	-418.8%	
Earth Sciences										
Overseas	40	48	56	49	48	45	77	91	51	127.5%
Domestic	472	387	467	380	292	285	282	302	-170	-36.0%
Sub-total	512	435	523	429	340	330	359	393	-119	-23.2%
Overseas % of All	7.8%	11.0%	10.7%	11.4%	14.1%	13.6%	21.4%	23.2%	-42.9%	
Biological Sciences										
Overseas	380	452	561	669	724	767	852	850	470	123.7%
Domestic	3423	3636	3720	3531	3431	3300	3406	3296	-127	-3.7%
Sub-total	3803	4088	4281	4200	4155	4067	4258	4146	343	9.0%
Overseas % of All	10.0%	11.1%	13.1%	15.9%	17.4%	18.9%	20.0%	20.5%	137.0%	
Other Natural and Physical Sciences										
Overseas	780	930	1371	1647	1812	2052	2022	2038	1258	161.3%
Domestic	6525	6448	6924	7454	7780	7949	7966	7963	1438	22.0%
Sub-total	7305	7378	8295	9101	9592	10001	9988	10001	2696	36.9%
Overseas % of All	10.7%	12.6%	16.5%	18.1%	18.9%	20.5%	20.2%	20.4%	46.7%	
All Natural & Physical Sciences FoEs										
Overseas	1393	1668	2232	2592	2870	3198	3310	3391	1998	143.4%
Domestic	11765	11909	12535	12652	12879	12885	13010	12776	1011	8.6%
Total	**13158**	**13577**	**14767**	**15244**	**15749**	**16083**	**16320**	**16167**	**3009**	**22.9%**
Overseas % of All	10.6%	12.3%	15.1%	17.0%	18.2%	19.9%	20.3%	21.0%	66.4%	

Table 9										
Course Completions 2002 - 2009	**Course Completions 2002 - 2009: Natural and Physical Sciences Students - PhDs by Citizenship Status**									
Field of Education / Citizenship Status	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**Growth - No.**	**Growth - %**
Mathematical Sciences										
Overseas	13	16	24	15	12	17	24	23	10	76.9%
Domestic	53	69	47	59	66	50	68	52	-1	-1.9%
Sub-total	66	85	71	74	78	67	92	75	9	13.6%
Overseas % of All	19.7%	18.8%	33.8%	20.3%	15.4%	25.4%	26.1%	30.7%	111.1%	
Physical Sciences										
Overseas	19	18	20	18	34	29	34	39	20	105.3%
Domestic	91	121	101	104	90	88	115	112	21	23.1%
Sub-total	110	139	121	122	124	117	149	151	41	37.3%
Overseas % of All	17.3%	12.9%	16.5%	14.8%	27.4%	24.8%	22.8%	25.8%	48.8%	
Chemical Sciences										
Overseas	18	23	19	31	36	38	38	48	30	166.7%
Domestic	152	139	132	121	136	131	129	127	-25	-16.4%
Sub-total	170	162	151	152	172	169	167	175	5	2.9%
Overseas % of All	10.6%	14.2%	12.6%	20.4%	20.9%	22.5%	22.8%	27.4%	600.0%	
Earth Sciences										
Overseas	18	14	18	18	20	17	21	27	9	50.0%
Domestic	59	68	87	82	65	57	46	56	-3	-5.1%
Sub-total	77	82	105	100	85	74	67	83	6	7.8%
Overseas % of All	23.4%	17.1%	17.1%	18.0%	23.5%	23.0%	31.3%	32.5%	150.0%	
Biological Sciences										
Overseas	71	83	87	68	86	113	96	112	41	57.7%
Domestic	400	468	447	411	450	456	499	474	74	18.5%
Sub-total	471	551	534	479	536	569	595	586	115	24.4%
Overseas % of All	15.1%	15.1%	16.3%	14.2%	16.0%	19.9%	16.1%	19.1%	35.7%	
Other Natural and Physical Sciences										
Overseas	27	31	54	55	60	76	59	75	48	177.8%
Domestic	141	156	195	274	233	297	239	243	102	72.3%
Sub-total	168	187	249	329	293	373	298	318	150	89.3%
Overseas % of All	16.1%	16.6%	21.7%	16.7%	20.5%	20.4%	19.8%	23.6%	32.0%	
All Natural & Physical Sciences FoEs										
Overseas	166	185	222	205	248	290	272	324	158	95.2%
Domestic	896	1021	1009	1051	1040	1079	1096	1064	168	18.8%
Total	**1062**	**1206**	**1231**	**1256**	**1288**	**1369**	**1368**	**1388**	**326**	**30.7%**
Overseas % of All	15.6%	15.3%	18.0%	16.3%	19.3%	21.2%	19.9%	23.3%	48.5%	

Table 10

Course Completions 2002 - 2009

Course Completions 2002 - 2009: Natural and Physical Sciences Students - All Course Levels by Gender

Field of Education / Gender	2002	2003	2004	2005	2006	2007	2008	2009	Growth - No.	Growth - %
Mathematical Sciences										
Female	269	286	264	244	249	279	288	282	13	4.8%
Male	413	416	411	422	440	449	429	433	20	4.8%
Sub-total	682	702	675	666	689	728	717	715	33	4.8%
Female % of All	39.4%	40.7%	39.1%	36.6%	36.1%	38.3%	40.2%	39.4%	39.4%	
Physical Sciences										
Female	86	118	103	89	106	92	87	83	-3	-3.5%
Male	253	344	318	318	351	343	348	328	75	29.6%
Sub-total	339	462	421	407	457	435	435	411	72	21.2%
Female % of All	25.4%	25.5%	24.5%	21.9%	23.2%	21.1%	20.0%	20.2%	-4.2%	
Chemical Sciences										
Female	216	210	261	200	243	247	246	219	3	1.4%
Male	301	302	311	241	273	275	317	282	-19	-6.3%
Sub-total	517	512	572	441	516	522	563	501	-16	-3.1%
Female % of All	41.8%	41.0%	45.6%	45.4%	47.1%	47.3%	43.7%	43.7%	-18.8%	
Earth Sciences										
Female	186	148	174	176	124	144	139	142	-44	-23.7%
Male	326	287	349	253	216	186	220	251	-75	-23.0%
Sub-total	512	435	523	429	340	330	359	393	-119	-23.2%
Female % of All	36.3%	34.0%	33.3%	41.0%	36.5%	43.6%	38.7%	36.1%	37.0%	
Biological Sciences										
Female	2321	2486	2625	2577	2533	2375	2477	2410	89	3.8%
Male	1482	1602	1656	1623	1622	1692	1781	1736	254	17.1%
Sub-total	3803	4088	4281	4200	4155	4067	4258	4146	343	9.0%
Female % of All	61.0%	60.8%	61.3%	61.4%	61.0%	58.4%	58.2%	58.1%	25.9%	
Other Natural and Physical Sciences										
Female	4161	4235	4846	5293	5526	5792	5692	5605	1444	34.7%
Male	3144	3143	3449	3808	4066	4209	4296	4396	1252	39.8%
Sub-total	7305	7378	8295	9101	9592	10001	9988	10001	2696	36.9%
Female % of All	57.0%	57.4%	58.4%	58.2%	57.6%	57.9%	57.0%	56.0%	53.6%	
All Natural & Physical Sciences FoEs										
Female	7239	7483	8273	8579	8781	8929	8929	8741	1502	20.7%
Male	5919	6094	6494	6665	6968	7154	7391	7426	1507	25.5%
Total	**13158**	**13577**	**14767**	**15244**	**15749**	**16083**	**16320**	**16167**	**3009**	**22.9%**
Female % of All	55.0%	55.1%	56.0%	56.3%	55.8%	55.5%	54.7%	54.1%	49.9%	

Table 11

Course Completions 2002 - 2009

Course Completions 2002 - 2009: Natural and Physical Sciences Students - PhDs by Gender

Field of Education / Gender	2002	2003	2004	2005	2006	2007	2008	2009	Growth - No.	Growth - %
Mathematical Sciences										
Female	17	23	23	15	23	19	33	31	14	82.4%
Male	49	62	48	59	55	48	59	44	-5	-10.2%
Sub-total	66	85	71	74	78	67	92	75	9	13.6%
Female % of All	25.8%	27.1%	32.4%	20.3%	29.5%	28.4%	35.9%	41.3%	155.6%	
Physical Sciences										
Female	24	47	38	35	41	34	35	31	7	29.2%
Male	86	92	83	87	83	83	114	120	34	39.5%
Sub-total	110	139	121	122	124	117	149	151	41	37.3%
Female % of All	21.8%	33.8%	31.4%	28.7%	33.1%	29.1%	23.5%	20.5%	17.1%	
Chemical Sciences										
Female	65	58	64	60	77	78	64	69	4	6.2%
Male	105	104	87	92	95	91	103	106	1	1.0%
Sub-total	170	162	151	152	172	169	167	175	5	2.9%
Female % of All	38.2%	35.8%	42.4%	39.5%	44.8%	46.2%	38.3%	39.4%	80.0%	
Earth Sciences										
Female	24	28	33	41	26	27	19	31	7	29.2%
Male	53	54	72	59	59	47	48	52	-1	-1.9%
Sub-total	77	82	105	100	85	74	67	83	6	7.8%
Female % of All	31.2%	34.1%	31.4%	41.0%	30.6%	36.5%	28.4%	37.3%	116.7%	
Biological Sciences										
Female	236	297	294	249	315	311	346	327	91	38.6%
Male	235	254	240	230	221	258	249	259	24	10.2%
Sub-total	471	551	534	479	536	569	595	586	115	24.4%
Female % of All	50.1%	53.9%	55.1%	52.0%	58.8%	54.7%	58.2%	55.8%	79.1%	
Other Natural and Physical Sciences										
Female	79	93	107	155	144	182	151	167	88	111.4%
Male	89	94	142	174	149	191	147	151	62	69.7%
Sub-total	168	187	249	329	293	373	298	318	150	89.3%
Female % of All	47.0%	49.7%	43.0%	47.1%	49.1%	48.8%	50.7%	52.5%	58.7%	
All Natural & Physical Sciences FoEs										
Female	445	546	559	555	626	651	648	656	211	47.4%
Male	617	660	672	701	662	718	720	732	115	18.6%
Total	**1062**	**1206**	**1231**	**1256**	**1288**	**1369**	**1368**	**1388**	**326**	**30.7%**
Female % of All	41.9%	45.3%	45.4%	44.2%	48.6%	47.6%	47.4%	47.3%	64.7%	

Table 12

Higher Education Enrolments 2002 - 2009: PhD Student Enrolments: All Fields of Education

Field of Education	2002	2003	2004	2005	2006	2007	2008	2009	Growth - No.	Growth - %
Natural and Physical Sciences	6553	6884	7317	8134	8404	8677	8730	9163	2610	39.8%
Information Technology	1000	1134	1359	1497	1619	1537	1528	1602	602	60.2%
Engineering and Related Technologies	3374	3699	3985	4110	4199	4340	4547	5047	1673	49.6%
Architecture and Building	425	468	472	469	513	525	550	617	192	45.2%
Agriculture, Environmental and Related Studies	1517	1581	1629	1760	1815	1869	2063	2121	604	39.8%
Health	4663	4976	5218	4736	5185	5533	5618	5976	1313	28.2%
Education	3380	3454	3428	3490	3490	3499	3445	3415	35	1.0%
Management and Commerce	3008	3128	3242	3359	3459	3521	3494	3606	598	19.9%
Society and Culture	8957	9163	9530	9908	10214	10284	10612	10881	1924	21.5%
Creative Arts	1163	1388	1505	1490	1613	1642	1779	1864	701	60.3%
Total	**34040**	**35875**	**37685**	**38953**	**40511**	**41427**	**42366**	**44292**	**10252**	**30.1%**
Natural and Physical Sciences % of Total	**19.3%**	**19.2%**	**19.4%**	**20.9%**	**20.7%**	**20.9%**	**20.6%**	**20.7%**	**25.5%**	

Source: DEST/DEEWR Aggregated Data Set 'UEAGyyyy' for years 2002 - 2009

These are the official figures. Those in Sustaining Science were adjusted for NPS to take account of changes in the classification schemes at Monash that affected the time series

Table 13

Higher Education Enrolments 2002 - 2009: **PhD Student Enrolments: Natural and Physical Sciences**

Field of Education	2002	2003	2004	2005	2006	2007	2008	2009	Growth - No.	Growth - %
Mathematical Sciences	414	441	475	480	495	503	498	534	120	29.0%
Physical Sciences:										
Physical Sciences - not specified	73	85	95	96	53	54	61	80	7	9.6%
Physics	604	628	658	684	771	788	790	831	227	37.6%
Astronomy	25	38	71	78	88	89	90	78	53	212.0%
Sub-total Physical Sciences	**702**	**751**	**824**	**858**	**912**	**931**	**941**	**989**	**287**	**40.9%**
Chemical Sciences	853	882	926	904	989	1006	1059	1138	285	33.4%
Earth Sciences	629	618	609	527	492	478	480	527	-102	-16.2%
Biological Sciences	2802	2973	3169	2945	3584	3712	3748	3906	1104	39.4%
Other Natural and Physical Sciences#	1153	1219	1314	2420	1932	2047	2004	2069	916	79.4%
Total	**6553**	**6884**	**7317**	**8134**	**8404**	**8677**	**8730**	**9163**	**2610**	**39.8%**
Physical Sciences % of Total	**10.7%**	**10.9%**	**11.3%**	**10.5%**	**10.9%**	**10.7%**	**10.8%**	**10.8%**	**11.0%**	

Source: DEST/DEEWR Aggregated Data Set 'UEAGyyyy' for years 2002 - 2009

These are the official figures. Those in Sustaining Science were adjusted for NPS to take account of changes in the classification schemes at Monash that affected the time series

Includes courses in '01 Natural and Physical Sciences - General', that universities did not classify more specifically

Appendix 12 AIP accredited courses

AIP Accredited Courses (For the five year period 2007-2011)

Institution	Accredited Programs	Year Accredited
Monash University	• Bachelor of Science with major in Physics with at least 18 points of Physics units at level 3	2007
University of Newcastle	• Bachelor of Science with major in Physics • Bachelor of Science with major in Photonics	2007
Queensland University of Technology	• QUT SC01 Bachelor of Applied Science majoring in Physics, • Double-degree courses, which include all of the mandatory units contained within the SC01 Physics major.	2008
Macquarie University	• Bachelor of Science majoring in Physics • Bachelor of Arts majoring in Physics • Combined Bachelor of Science and Diploma of Education for Science Teachers majoring in Physics • Combined Bachelor of Arts and Diploma of Education for Science Teachers majoring in Physics • Bachelor of Science majoring in Mathematical Physics • Bachelor of Arts majoring in Mathematical Physics • Bachelor of Science in Astronomy and Astrophysics • Bachelor of Optical Technology	2008
University of New South Wales	• BSc, with a major in Physics (UNSW course number 3920 • b) BSc Advanced Science (UNSW course number 3972), with either a plan in Physics; Physics and Astronomy; Physics and Computer Science; or Mathematical Physics, • or any double degrees incorporating either a) or b).	2008
Murdoch University	• Bachelor of Science with a major in Physics	2008
University of Western Australia	• Bachelor of Science (Physical Science) with a major in Physics • Bachelor of Science/Bachelor of Engineering with a science major in Physics • Bachelor of Science/Bachelor of Arts with a science major in Physics • Bachelor of Science/Bachelor of Education with a science major in Physics • Bachelor of Science/Bachelor of Commerce with a science major in Physics	2008
Australian National University	• Bachelor of Science with a major in either, Physics, Theoretical Physics. • Bachelor of Science with a double major in Physics, or any two of, Physics, Theoretical Physics, or Mathematical Physics. • Bachelor of Science with majors in Physics and Astronomy • Bachelor of Engineering/Bachelor of Science with a major in Physics • Bachelor of Science (Advanced) (Honours) with a major in Physics	2009

	• Combined Sciences degrees, in which studies in another areas are combined with Science, majoring in Physics • Bachelor of Philosophy with a major in Physics	
Flinders University	• Bachelor of Science with a Major in Physics (3 years) • Bachelor of Science with an Extended Major in Physics (3 years) • Bachelor of Science (Honours) in Physics High Achievers Program (4 years) • Bachelor of Science in Nanotechnology (Honours) Quantum Structures Stream – (4 years)	2009
Griffith University	• Bachelor of Science with a Physics Major • Bachelor of Science (Advanced) with a Physics Major • Bachelor of Science (Advanced with Honours) in Physics • Bachelor of Photonics and Nanoscience • Bachelor of Science with Honours in Physics (Accelerated)	2009
James Cook University	• Bachelor of Science with a major in Physics. • Bachelor of Arts/Bachelor of Science Joint Degree with a major in Physics. • Bachelor of Education/Bachelor of Science Joint Degree with a major in Physics. • Bachelor of Engineering/Bachelor of Science Joint Degree with a major in Physics • Bachelor of Psychology/Bachelor of Science Joint Degree with a major in Physics.	2009
University of Queensland	• Bachelor of Science with a majors in, Physics, Biophysics, Physics and Computational Science, and the Extended Major in Physics	
University of Tasmania	• Bachelor of Science with Major in Physics, and the Science combined degree with major in Physics	
University of Technology Sydney	• Bachelor of Science in Applied Physics • Bachelor of Science in Nanotechnology	
University of Adelaide	• Bachelor of Science with a major in Physics or Theoretical Physics • Bachelor of Science (High Performance Computational Physics) (Honours) • Bachelor of Science (Optics and Photonics) • Bachelor of Science (Space Science and Astrophysics) • Bachelor of Engineering (Electrical and Electronic)/Bachelor of Science (Physics)	2010
Kuwait University	• Bachelor of Science in Physics • Bachelor of Science in Engineering Physics (Digital Systems) • Bachelor of Science in Engineering Physics (Remote Sensing) • Bachelor of Science in Engineering Physics (Lasers and Optical Communication)	2010
Latrobe University	• Bachelor of Science (Hons)/Master of Nanotechnology • Bachelor of Science (Physics major) • Bachelor of Science (Specialization in space Science) • Bachelor of Nanotechnology/Bachelor of Science • Double degrees with a Bachelor of Science (Physics major)	2010
The University of	• Bachelor of Science with a major in, Physics, Chemical Physics or	2010

Melbourne	Mathematical Physics.	
The University of Sydney	• Bachelor of Science • Bachelor of Science (Advanced) • Bachelor of Science (Advanced Mathematics) • Bachelor of Liberal Arts and Science (BLAS) • Any combined degree program allowing a major in Physics.	2010
University of Wollongong	• Bachelor of Science (Physics) – Basic/Core Major Program in Physics • Bachelor of Medical and Radiation Physics • Bachelor of Science (Nuclear Science and Technology) • Bachelor of Science (Photonics) • Bachelor of Science (Physics and Mathematics) • Bachelor of Science Advanced (Physics) • Bachelor of Science Honours (Physics) • Bachelor of Medical and Radiation Physics Advanced • All Double Degrees that include the Basic /Core Major in Physics	2010

Appendix 13 Case studies

Some text taken from CSIRO (http://www.csiro.au/), Wikipedia (http://en.wikipedia.org/), Australian Academy of Science (http://www.science.org.au/)

Case Study: BHP's FALCON

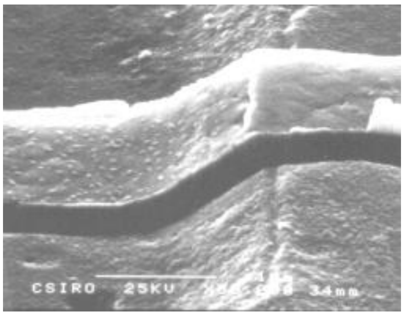
The FALCON project started in 1991. BHP Billiton's Research Group lead by Edwin van Leeuwen and Gravity Diamonds Limited Managing Director, Phillip Harman, developed and commercialised the Falcon™ gravity gradiometer technology by 2000. It was the first airborne gravity gradiometer designed specifically for application to minerals exploration from the air and complemented other airborne geophysical technologies that have been available since the 1950's. It is used to map the density distribution of rock formations within the top kilometre of the earth's crust and to locate small variations in the earth's gravity that are associated with specific mineral deposits and hydrocarbon resources.

CSIRO's LANDTEM™

Deeply buried deposits of minerals such as nickel, gold and silver are of great interest to the mineral industry because most ore found to date has been on or just below the surface. However, these deposits can be hard to find because conventional coil magnetic sensors are not sensitive enough. In Australia, exploration for these minerals is even more difficult because the overburden (material above the deposit) is often highly conductive.

CSIRO's LANDTEM™ is a highly portable exploration tool which can spot the difference between ore and conductive overburden, even when the ore body is deeply buried. LANDTEM™ uses highly sensitive magnetic sensors known as SQUIDs (Superconducting Quantum Interference Devices). LANDTEM™ is helping unearth large deposits of nickel sulphide and silver worth hundreds of millions of dollars. It has also:

- Found several previously undetected large nickel sulphide deposits in Western Australia
- Cut exploration costs by 30 per cent to a company working in difficult terrain in northern Quebec in Canada
- Clarified data at BHP Billiton's Cannington silver mine in Queensland.



Philip K Chapman, Australian born US astronaut

Philip Chapman was born in 1935. He graduated from Parramatta High School in Parramatta, N.S.W., received a Bachelor of Science degree in Physics and Mathematics from the University of Sydney in 1956; and from the Massachusetts Institute of Technology a Master of science degree in Aeronautics and Astronautics in 1964, and in1967a Doctorate of Science in Instrumentation from the same institution.

Chapman served with the Royal Australian Air Reserve from 1953 to 1955. From 1956 to 1957, he worked for Philips Electronics Industries Pty Ltd in Sydney and then joined the Australian National Antarctic Research Expedition (IGY) serving for two years as an auroral/radio physicist. From 1960 to 1961, he was an electro-optics staff engineer in flight simulators for Canadian Aviation Electronics Limited in Dorval, Quebec. His next assignment was as a staff physicist at the Massachusetts Institute of Technology, where he worked in electro-optics, inertial systems, and gravitational theory until the summer of 1967. He has logged 1000 hours flying time in jet aircraft.

After gaining US citizenship Chapman was selected as a scientist-astronaut by NASA in August 1967. After initial academic training and a 53-week course in flight training at Randolph Air Force Base, Texas, he was involved in preparations for lunar missions, serving in particular as mission scientist for the Apollo 14 mission. Because of the lack of spaceflight opportunities for scientist-astronauts in the 1967 intake, Dr. Chapman left NASA in July 1972. Subsequently he worked with Arthur D. Little Company, Inc., Cambridge, Massachusetts and in a number of commercial ventures and advisory roles to the US government. Chapman is now Chief Scientist of Transformational Space Corporation("t/Space," Reston, Virginia).. Under a $6 million contract from NASA, t/Space has developed a plan to support the International Space Station (ISS), after the shuttles retire in 2010, using spacecraft owned and operated by private enterprise, due to the adoption by NASA of commercial support as its baseline plan for the ISS.

CSIRO’s Wireless LAN technology

John O’Sullivan led the system design team for the world’s first 802.11a (WiFi) chipset that was subsequently developed and commercialised by Radiata Networks.

John O’Sullivan received a Bachelor of Science in Physics from Sydney University in 167, and a Bachelor of Engineering with first class Honours and the University Medal in 1969 and PhD in Electrical Engineering in 1974, both from the same institution.

CSIRO’s wireless invention lies at the heart of what is now the most popular way to connect computers without wires. Forecasters predict that there are likely to be more than a billion devices sold worldwide over the next few years using this technology.

The invention came out of CSIRO's pioneering work in radioastronomy. That work involved complex mathematics known as 'fast Fourier transforms' as well as detailed knowledge about radio waves and their behaviour in different environments.

Indoor environments are particularly difficult for the rapid exchange of large amounts of data using radio waves. CSIRO solved these problems in a unique way at a time when many of the major communications companies around the world were trying, but with less success, to solve the same problem.

CSIRO's invention was granted a US patent in 1996. There are corresponding patents in 18 other countries.

The technology was first embodied in an industry standard in 1999 (called IEEE 802.11a) and later in other standards (IEEE 802.11g and IEEE 802.11 draft n).

John O'Sullivan's career spans the two disciplines Physics and Engineering and work in both government funded research and industrial research. After completing his PhD in Sydney he took an appointment in the Foundation for Radio Astronomy in the Netherlands (now ASTRON). He went on to become the Head of their Engineering group making major contributions in the electronics and signal and image processing areas.

In 1983, he returned to Australia for research at CSIRO and played an important early role in the initial conception of the Australia Telescope receiving systems. He was primarily charged with setting up a new Signal Processing group at the Division of Radiophysics.

This group under his direction set out to find applications of processing skills and technologies for the wider community and led to the group making significant contributions, together with various commercial partners and customers, in areas such as image processing for medical and geophysical applications, underground mine safety, communications systems and radar processing systems.

After his demonstration of the Wireless LAN system, Dr O'Sullivan left CSIRO in 1995 to join News Ltd as their Australian Director of Technology. During this period, he was a member of the PMSEIC working party 'Connecting Australians: Opportunities for a New Wireless Age'.

Following the formation of Radiata in 1997, he returned to Australia to join them as Vice President of Systems Engineering. He continued this role for some time after the acquisition of Radiata by Cisco in 2001.

More recently, Dr O'Sullivan returned to CSIRO to work on the system design for the Square Kilometre Array.

His major scientific achievements were:

- Achieved an eight-fold increase of the bandwidth processing capacity of the Westerbork Radio Telescope as project leader for the digital continuum backend receiver
- Participated in a series of innovative experiments to detect exploding black holes and other short time astronomical events
- Developed an intellectual underpinning for adaptive optics in light telescopes and redundant baseline interferometer in radio telescopes
- With Austek Microsystems created a fast Fourier transform computer chip. This VLSI chip consisted of 160,000 transistors and performed real time transforms at rates up to 2.5 Msamples/s
- Influential role in the system design for the Australia Telescope
- Led a CSIRO team comprising Graham Daniels, John Deane, Diethelm Ostry, Terry Percival who together invented a patented technology that uses fast Fourier transform and other techniques to enable fast, robust wireless networking in the home and office.
- Over 40 scientific and technical papers at numerous industry conferences
- Granted 12 patents in the area of special purpose FFT processors, Wireless LANs and antennas

David Mills and AUSRA – Solar Power Generation - From Sydney University to California to France – and back to Australia

A media release by AREVA, a France based multinational carbon-free power generator company, says this: "AREVA Solar has been awarded a major contract to install a 44 megawatt solar thermal augmentation project at a 750 megawatt coal-fired power station in Queensland, Australia, representing the largest solar project in the Southern Hemisphere and the world's largest solar/coal-fired power augmentation project. AREVA Solar's Australian-pioneered Compact Linear Fresnel Reflector (CLFR) technology will be installed at CS Energy's Kogan Creek Power Station. Construction of the solar boost project is scheduled to begin in the first half of 2011, with commercial operation planned for 2013. The AU$104.7 million Kogan Creek Power Station Solar Boost Project represents the largest deployment of AREVA's solar thermal technology in the world and will generate an additional 44,000 megawatt hours of electricity per year. AREVA is saying: "By using energy from the sun with AREVA's solar booster application, we will make the coal-fired plant more fuel-efficient and reduce its greenhouse intensity – avoiding the production of 35,600 tonnes of greenhouse gas emissions annually." The project will create 120 jobs during the construction period.

The principle of the Compact Linear Fresnel Reflector (CLFR) technology is very simple and can be used in a variety of industrial applications, including enhanced oil recovery, petroleum refining and food processing: Rows of flat mirrors that follow the path of the sun are arranged in a one-square-mile grid. The mirrors reflect the sun's heat onto water-filled pipes above, creating steam that cranks a turbine in a nearby power plant. The electricity produced does not produce a molecule of greenhouse gas. Unlike photovoltaic (PV) or other concentrated solar technologies, which lose output immediately when clouds come over, the technology has 20 to 30 minutes of stored capacity, so it can adjust to weather changes or other factors affecting the electric grid.

The Compact Linear Fresnel Reflector (CLFR) technology of this power plant has been invented by David Mills who has been working in non-imaging optics, solar thermal energy, and PV systems for over 32 years.

Mills graduated with a Bachelor of Science in Physics and a PhD in non-imaging optics from the University of New South Wales. He proceeded to lead the Solar Energy Group in the School of Physics at the University of Sydney that developed and licensed the evacuated-tube solar water heater technology, which comprises 60 per cent of the world's solar collectors. Mills originated and ran the research program that in 1991, with colleague Dr. Q-C. Zhang, developed the most advanced sputtered double cermet selective absorber coating, which is now used in evacuated tube receivers by China's largest solar company, Himin. He developed or co-developed other commercial systems including the Prism solar concentrator (Sol X) and the "S" evacuated tube reflecting system (Solahart). A solar sterilizer design he originated won a World Health Organization award in 2002, and he was a finalist in the 2002 World Technology Awards for Energy.

Mills, with a friend, a professor of engineering at the University of NSW, formed a company and invested their own money to cover the patents for the IP Compact Linear Fresnel Reflector (CLFR) that they had purchased for very little money from the University of Sydney. The patent costs of $80,000 were initially paid out of their personal funds which was hard at the time as they only had two incomes to support that. But they had some faith in it and eventually got a grant from the government.

In 2002 Mills and his company built a small 1.5 MW demonstrator solar power station in NSW next to the coal fired Liddell power station in the Hunter Valley. It was the first of its kind ever built commercially in the world. At the time investors in Silicon Valley were looking for solar projects because of the incentives that had been put out by the government there. Eventually Mills made an initial deal for $43 million and started a new company in the United States, Ausra, which bought these shares in the Australian company.

The group of investors that invested in Ausra were from the US, Canada, the UK and Starfish in Australia, and they all were very closely looking at the value of what they obtained from this deal and what it might obtain.

Over time the company got additional investment of more than US$130 million and were able to employ very good research and development and engineering staff from the Bay area, using people from Stanford University, Berkeley and MIT. They were able to employ the best people and made a lot of engineering progress on the design, but also a lot of ideas-based product progress as well. David Mills states that this could have been done in Australia also in principle, as there are very good people here, but that level of money just wasn't available to pay for it. In the company in the United States there were two mathematicians, plus physicists, plus engineers working together and there was basic work going on at any stage in that R&D department.

In February 2010 the French conglomerate AREVA announced the 100% acquisition of Ausra, This acquisition launched AREVA's new global solar energy business and reflects AREVA's strategic objective to be the world leader in concentrated solar power (CSP) and its push into diversification in its renewable energy portfolio of wind and biomass power generation.

AREVA now has won the contract for Australia's largest solar plant in Queensland. So the technology is actually returning to Australia with the construction of the largest solar plant ever built in the country.

CSIRO's PLASCON™ waste destruction system

The PLASCON™ waste destruction system, developed by CSIRO and Siddons Ramset Pty Ltd, uses an arc plasma (like that used in arc welding) to destroy such substances as:

- Fluorocarbon greenhouse gases;
- Toxic organic chemicals such as polychlorinated biphenyls (PCBs);
- Ozone-depleting substances such as chlorofluorocarbons (CFCs) and halons (bromochlorofluorocarbons), which were once used as fire extinguishers.

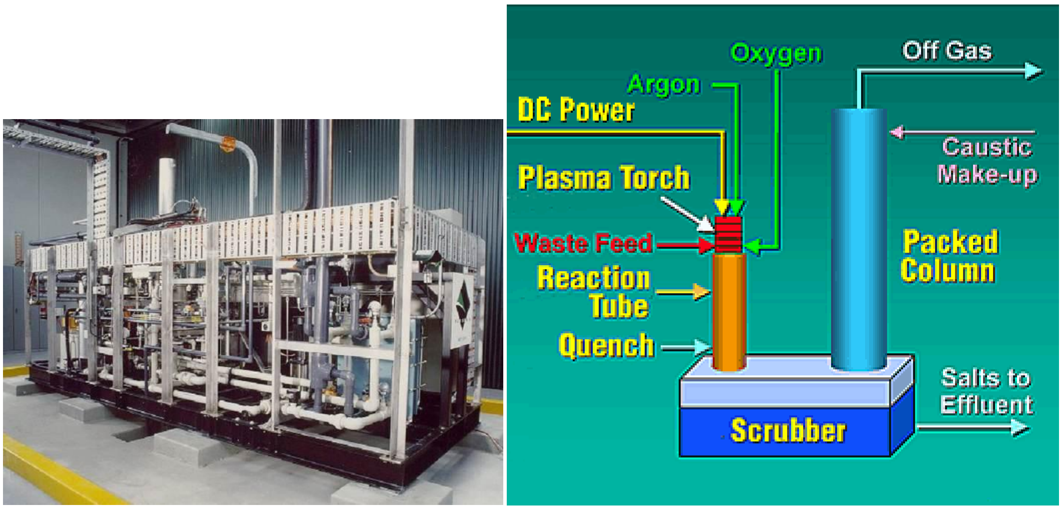
The development of the PLASCON process required an intensive R&D effort that involved physicists (for both experiments and computational modelling), chemists, and electrical, chemical and mechanical engineers. The lead scientists in CSIRO were Tony Murphy, Tony Farmer and Trevor McAllister.

There are currently twelve PLASCON units around the world:

- Two at Nufarm in Melbourne, Victoria, destroying waste liquid from the production of the herbicide 2, 4-D.
- One at the Australian National Halon Bank in Melbourne, Victoria, destroying Australasian stockpiles of halons and CFCs.
- One at BCD Technologies in Brisbane, Queensland destroying PCBs and insecticides.
- One originally installed at DASCEM Europe's plant in the United Kingdom (UK) to destroy Europe's stockpile of halons and transferred to Mexico's Quimobasicos company where it now destroys trifluoromethane. It has recently been joined by a second unit.
- One at Honeywell Specialty Chemicals, Louisiana, USA, destroying fluorocarbons
- Four at Mitsubishi Chemical Company in Japan, destroying the company's stockpile of PCB–kerosene mixtures.
- One in Ohio, USA, destroying halons.

The case of trifluoromethane is particularly interesting. Trifluoromethane is a greenhouse gas formed as a by-product of hydrochlorofluorocarbon (HCFC) production. HCFCs are CFC replacement chemicals that are being phased out in the developed world, but whose use is permitted until 2040 in the developing world. Until recently, trifluoromethane was released into the atmosphere. However, under the Kyoto Protocol, carbon credits can be paid to developing countries for projects that reduce greenhouse emissions.

Trifluoromethane has a global warming potential 11 700 times that of carbon dioxide (CO2). At A$20 per tonne of CO2, the rate per tonne of trifluoromethane is well over A$200 000. This exceeds the cost of destruction by more than a factor of twenty and PLASCON™ destroys about 185 tonnes per year. Destroying this much trifluoromethane is the equivalent of removing the CO2 emissions of a 300 megawatt coal-fired plant or 500 000 cars each year.



Figures: Schematic of the PLASCON process, and photo of the PLASCON plant at the Australian National Halon Bank

Jacob Haimson and Haimson Research Corporation

Jacob Haimson was born in Melbourne in 1928, and graduated from the Royal Melbourne Technical College in 1945 as an Electrical Engineer, and from the University of Melbourne in 1948 with Honours in Physics. He moved to Metropolitan Vickers in Manchester in 1950 to work on medical linear accelerators. In 1959 Haimson joined the accelerator research program of Varian Associates in the US, and in the same year was invited to work at Stanford University with Edward Ginzton and Henry Kaplan on the development of the first medical linear accelerator. In 1970, Haimson formed his own scientific instrument company, the Haimson Research Corporation in Santa Clara, California, which focuses on the design of electron linear accelerators. Jacob Haimson is world renowned for his contribution to accelerator technologies and the world's foremost research organisations seek his input and instruments. Jacob Haimson continues to actively participate in the scientific community, most recently in the 2011 Collaboration Meeting on X-band Accelerator Structure Design at the SLAC National Accelerator Laboratory in the US. In November 2010, he endowed a professorship in radiation oncology at Stanford University, and the first Jacob Haimson Professor is Lei Xing.

Sir Alan Walsh, Atomic absorption spectroscopy – an Australian invention

(Sir) Alan Walsh born in 1916 in the UK and concluded his undergraduate and postgraduate studies in the Physics Department at the Manchester College of Technology in the UK. He was the originator and developer of the atomic absorption method of chemical analysis, which has been described as 'the most significant advance in chemical analysis' in the twentieth century. Alan Walsh became the leader of the Spectroscopy Section of the CSIRO Division of Chemical Physics in Melbourne from 1946-57 and Assistant Chief of the Division from 1958-76. This Division that had the aim to apply modern physical techniques to the solution of chemical problems. His interest in atomic absorption spectroscopy was a result of two interacting experiences; one of the spectrochemical analysis of metals over the period 1939-46; the other of molecular spectroscopy up to 1952.

The first public demonstration of a working atomic absorption instrument was in March 1954 at an exhibition of scientific instruments held by the Victorian Division of the (then British) Institute of Physics at the University of Melbourne. Atomic absorption provided a quick, easy, accurate and highly sensitive method of determining the concentrations of more than sixty-five of the elements, rendering traditional wet-chemical methods obsolete. The method has since found important application world-wide in areas as diverse as medicine, agriculture, mineral exploration, metallurgy, food analysis, biochemistry, the wine industry and environmental control.

Bringing the method from the laboratory into commercial production was not an easy path for Walsh. An attempt to commercialise the technology via a license agreement through Hilger and Watts in the UK failed and it took several years until in 1962 Techtron Pty Ltd, a small Australian company based in Mulgrave was again interested in commercialising the instrumentation.

The first spectrometer based on his Walsh's design was produced by Techtron in 1964. In August 1965, Techtron Appliances Pty Ltd merged with Atomic Spectral Lamps Pty Ltd to form Techtron Pty Ltd, which manufactured the Model AA-4 with a synchronously tuned amplifier and a nitrous oxide-acelylene burner. This was followed by a period of rapid growth, with staff increasing to around 200 in 1966.

Techtron Pty Ltd was approached by Varian Associates, a successful instrument manufacturing company in Palo Alto, California, with an offer of acquisition, first a 50.5% holding and progressing to 100% over five years. This was followed by further rapid growth, with sales increasing at an average of 30% a year for the next six years and staff growing to 630 by 1972. The company continued to become Varian Australia Pty Ltd, the second largest manufacturer of atomic absorption equipment in the world, exporting more than two-thirds of its output. Varian has now been acquired by Agilent Technologies.

Poseidon Scientific Instruments - The purest sine wave on the planet

In 1979 the University of Western Australia began developing ultra -low noise microwave oscillators as part of the detection system in resonant bar gravity wave detectors. At the core of these oscillators was a completely new class of electronic resonator – a sapphire whispering gallery mode resonator. This technology has since been developed by Poseidon Scientific Instruments (PSI), a Western Australian High Technology company, into the world's lowest noise microwave signal generator, being more than 1000 times lower noise than competing technologies. 20 years later these oscillators are still market leaders – in spite of massive investments by US and European agencies to develop competing technologies. *This technology is most easily thought of as a clock which meters out 10 billion clicks a second with extreme precision. The precision of the "clicks" enables the measurement of very fast events with a precision previously unattainable.*

Jesse Searls, founder and CEO of PSI, developed the first commercially viable prototype in the early 1990's whilst financing the development through sales of custom radio technologies and instruments for marine applications. The first commercial orders for the sapphire oscillators started in 1994 – after 4 years of international marketing effort and by 1998 the technology was considered the best "clock" on the market. After initial sales to the Japanese Measurement Laboratory, the US Navy and the US National Institute for Standards and Technology, more companies started to value this technology, including Boeing, Lockheed, Westinghouse and the US Army. PSI has generated $25 million in export income, mainly from the defence market where the oscillators are incorporated in the latest generation of radars, radars that a customer described as 'being able to see an object of the size of a tennis ball from 5000 km away'.

Jesse kept close relationships with the University of Western Australia via ARC Linkage grants with the goal to develop further technologies. However, it was not always plain sailing. Throughout the tech boom and bust cycle, the recession of the 1990s, the recent global financial crisis and the downturn in defence spending in the Western economies, this Australian company has seen its ups and downs but keeps spending 15% if its revenue on R&D, modelling itself on some of the most successful US companies.

Ron Bracewell

Bracewell [104] (1921-2007) AO, B.Sc., BE, ME, PhD (Physics) was born in Sydney, graduated from the University of Sydney with a B.Sc. in mathematics and physics and later added a Bachelor and Master of Engineering. During World War II Bracewell worked at the CSIRO in Sydney and developed microwave radar and voice modulation equipment. After the war he moved to the CSIRO's Radiophysics Laboratory and specialised in the field of radio astronomy. While at the Cavendish Laboratory, Cambridge (1946–1950), Bracewell worked on observation and theory of the upper and contributed to explaining solar effects. He moved to the USA and lectured in radio astronomy at the Astronomy Department of the University of California, Berkeley, and joined

[104] http://en.wikipedia.org/wiki/Ronald_N._Bracewell , accessed April 11, 2011.

the Electrical Engineering faculty at Stanford in December 1955. In 1974 he was appointed the first Lewis M. Terman Professor and Fellow in Electrical Engineering at Stanford University (1974–1979).

At Stanford Professor Bracewell constructed a microwave spectroheliograph (1961), a large and complex radio telescope which produced daily temperature maps of the sun reliably for eleven years, the duration of a solar cycle. This radio telescope automatically provided outputs in printed form, and therefore enabled global dissemination by teleprinter, and its daily solar weather maps were used by NASA to support the first manned moon landing. Later inventions were used to support missions to explore space and stars other than the sun and their planets.

In his research work in astronomy he developed an algorithm for the reconstruction of radio telescope images from space. This algorithm was subsequently used for the reconstruction of computer assisted X-ray tomography images in medical physics. This work had great impact on the progress of medical imaging and contributed greatly to the improvement of accuracy of medical diagnostics for detecting tumours through imaging and improved outcomes inpatient care. Bracewell continued to contribute his knowledge on the scientific advisory boards of medical instrument companies to further improve tomography scanners. For his work related to medical imaging he received rewards by the Institute of Medicine at the University of Sydney and the Heinrich Hertz medal.

Appendix 14 White papers

White papers are posted on the Physics Decadal Plan website:
http://www.physicsdecadalplan.org.au/