Submission to the Productivity Commission

Review of the role of public investment in Australian science

Submitted by the Graeme I Pearman
Director, Graeme Pearman Consulting Pty Ltd
August, 2006

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Preface

The author of this submission was engaged in publicly funded scientific research and research management for over 30 years[1]. During the 1990s he was head of a CSIRO Division, for some time leader of the Environmental and Natural Resources Divisions of CSIRO (~1100 staff) and member of the CSIRO Executive. In these roles he questioned, perhaps more than most, the apparent lack of clarity around the role of publicly funded scientific research, and in particular CSIRO. He published an article on the subject in 1996 and contributed a number of internal discussion documents during the 1990s[2].

The Productivity Commission Review of this issue is overdue. It will be argued that the current crisis within CSIRO has been at least in part a reflection of lack of appreciation of the pluralistic nature of the outcomes of that investment and thus the value proposition for maintaining or growing the investment. Australia's commitment to publicly funded science is based on, at best, a poorly constructed view of what the investment is for, and at worst, a short-term, ideological and narrow view of the role of Science in modern societies.

This submission can not be a comprehensive review of all the issues. Nor is it proposed that its views will be universally acceptable. Rather it will argue that the greatest omission has been the lack of an intellectual consideration of these roles and the intent of the investments. It is made in the hope that the Productivity Commission will at last stimulate the discussion necessary and that further investment will be made with a more shared and considered view of what is intended.

The author apologises for the length of the submission but hopes that the effort to read it will be worthwhile. He also would be happy to discuss the issues raised hearing with the Commission.

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[1] A brief curriculum vitae is provided in Annex 1.
[2] Pearman (1996). National Science:" national needs. In Nurturing Creativity in Science: Ideas on Foundation of Innovation. Osmond, C.B. and Pockley, P. (Edts.) Macmillan, Melbourne.

Executive Summary

Historically the practice of Science has contributed to a range of outcomes, the success of each is assessed differently, sometimes objectively and sometimes more subjectively.

The curiosity driven intent of individual scientists, often disciplinary and reductionist in nature, has, by and large, driven scientific direction and over four centuries. Yet the outcomes of this knowledge generation have culminated in enormous human benefit. It is unlikely that this approach will suddenly have lost value in the 21st century

In the latter part of the 20th century the value of the direct mining of accumulated knowledge and its application in innovative frameworks was realised. This demanded more integration, multidisciplinary research teams, collaboration between scientists and greater interface with non-scientific experts.

While a balance between the application-oriented Science and the direct generation of knowledge is necessary, there appears to be lack of clarity concerning the interdependencies and roles of, and desired investment levels in both approaches.

Knowledge generation through the scientific methodologies has pluralistic value for the community, and thus in turn underpins the need for shared community sponsorship and the need for public investment. This pluralism relates to diverse outcomes in:

- ***Wealth Generation***
- ***Knowledge reconnaissance***
- ***Supporting policy development, public and private sector***
- ***Underpinning scientific/technological literacy***
- ***Solution to problems***, and
- ***Expanding knowledge frontiers***.

A key component of any investment in Science is the expectation that it will deliver to the wealth of the Nation and of individual companies. But publicly funded investment should be in both knowledge generation and knowledge application. Knowledge generation is often more strategic and more risky and less likely to attract private sector investment, so that the National science agenda, through public funding, may well be required to support knowledge generation where otherwise market forces may fail.

Australia produces less than 2% of the world's new Science and technology. The rational response to this fact is the investment in Science and scientists for whom the main objective is to maintain intimate contact with the other 98% (knowledge reconnaissance) of emerging ideas, trends and opportunities. Only professional scientists will be able to identify this knowledge at its earliest time for the National advantage.

A most important value of publicly funded Science is its potential to provide fearless and independent views of the world. Such views constitute important advice that can be more strategic and less sectorally-biased as input to risk analysis and policy

development in both the private and public sector than that from more directly affected or interested parties. The fearlessness and independence of such advice is currently under serious threat.

Quality and strategically defensible policy, private and public, will only be as good as the expert advice by which it is underpinned. This raises serious issues concerning both the level of public investment in Science that has this role, and the medium by which this advice is conveyed to the policy-developing process.

Technology, based on scientific discovery and the innovation process underpins modern societies. But in the absence of community literacy with regards to the Science, there is a high probability that good ideas and opportunities may be threatened by public scepticism/concerns. Thus active participation in public communication of scientists is in the public good. There should be seen as part of the investment strategy for Science.

In the cases above, Science can contribute by being both innovative, defining directions and anticipating results from the perspective of Science itself, or responsive, working specifically on areas that have been defined by the perceived needs of a wider community. The latter is an important role, recognising that the community is beset by problems related to improving productivity and the sustainability of the environment that need to be solved for both wealth generation and wider community reasons. What is important, however, is that overemphasis on the latter can seriously stifle new discovery near the margins of existing disciplines or at their interception, if the less scientific literate community controls all of the scientific directions through priority or problem-solving research grants and contracts.

It is counterproductive to compartmentalise Science into a limited number of components, e.g. pure research and discovery, policy advice, application, collaboration innovation. They need to be viewed as a spectrum, in which institutions and individual scientists must operate as effectively as possible.

Contents

1. Rationale for this submission

In 2004 the Prime Minister of Australia, Mr John Howard MP, delivered to the Australian people, his innovation action plan, Backing Australia's Ability[3]. This new Government policy was strongly influenced by the Knowledge and Innovation Statement[4]. These were significant efforts to provide advice to Government on new initiatives and funding for Science and higher education, consistent with promoting an innovative society.

It is too early to assess the impact of the statement on the future of Science in this country. There remain questions concerning the real level of new funding, the mode of application of that funding, and indeed, whether the approach will deliver what was intended.

This document takes the position that the Statement on the one hand reflects an extremely narrow, non-strategic, sectorally self-serving and ideologically based outcome. The document calls for a more substantial, more intellectually charged approach, directed at a whole-of-Australia shared and targeted national Science strategy.

It is not that this author is well placed to address the gamut of issues that needs to be considered in such a strategic view. On the contrary it will be argued that the issue of the role of Science in past and future generations is highly pluralistic, often misunderstood. Further the view will be taken that Science operates by "licence" of the community in a rapidly changing set of contexts. These include the changing role of Government and the private sector, new visions of the role of universities, shifts in the balance of private and government financing of research, the application of research to economic outcomes, globalisation of opportunity, and a myriad of strategic threats and opportunities related to societal, economic and environmental futures.

It is this complexity itself that demands a comprehensive and broadly-based analysis of options for Science futures that can not be developed by narrow sectors of the community or with narrow perspectives of the role of Science.

With respect to CSIRO's current focus on capturing scientific knowledge for economic benefit it is argued that this is a huge, potentially dangerous experimentation with a national and publicly supported asset that is being undertaken on what are basically ideological grounds, in a vacuum, devoid of open debate concerning the overall benefit of this approach for Australia. There is a need for a shared and considered view concerning the fundamental question of: Why have such an Organisation and why make such an investment? This submission is made in the hope that the Productivity Commission may greatly assist this process.

In 2005, CSIRO is in effect bankrupt. After dispensing about 20% of its staff over the last decade or so it remains unable to meet its budgetary constraints with further

[3] The Innovation Statement. http://backingaus.innovation.gov.au/default2001.htm

[4] Evaluation of the Knowledge and Innovation Reforms Consultation Report.

redundancies likely. It has failed to make substantial increases in attracting so-called "external funding", despite very significant impacts on the culture and managerial diversion of staff in the attempt to do so. These failures need exposure, and these managerial approaches require assessment against rigorous performance indicators. The process and other cultural changes have led to early retirements, redundancy of productive and experienced senior staff and most importantly failure to attract young and mid-career scientists from overseas and the loss of mid-career scientists to Europe and North America.

This submission is made in the belief that these specific issues for CSIRO reflect a wider need for a more clearly defined rationale for the expenditure of public funds on Science, which appears to be the objective of this Productivity Commission Review.

In the last decade or so, significant government funding has been directed at the concept of Cooperative Research Centres (CRCs) the value of these was reviewed in what was a highly non-critical way. Significant unhappiness exists over the limitations of this CRC approach, yet in a climate of budgetary constraints, the main benefactors are reluctant to too openly discuss the real shortcomings. These included vagueness about the balance between knowledge generation and knowledge application, the neglect of public-good activities and the incredibly inefficient way of expending money through relatively small institutional arrangements with enormous overheads. This is compounded by the lack of continuity that does not reflect the real timescales of knowledge generation or application research, the real costs associated with CRCs driven by costly start-up and closed-down, a ridiculous level of internal review and governance and related demands of overheads on research staff. Serious questions should be asked about whether some of these targeted areas of research and application could not have been better approached through investment in existing research organisations (albeit with contractual expectations regarding corporation) or through an alternative model of funding.

2. The role of investment in Science

Ziman[5] points out that the rapid growth of Science and Technology funding for much of the past century was not sustainable. He argues that it is simply unreasonable to expect that Science will grow to take an ever increasing and ultimately major proportion of all national wealth generation. The stabilisation of support for Science around the world (albeit patchy and related to levels of development) that we now see, may well mean we have entered an inevitable "steady-state" condition. But Science by its very nature discovers new problems, themselves opportunities, faster than it solves problems. It is inherently geometric. Science and Technology have also further exacerbated the propensity for growth by enormous prospects and opportunities it has brought through such things as computing power, data access, sensing technology, etc. Further, all of this comes at a time when much of the technology itself is growing in cost, faster than wealth generation. The levelling off of support rests uneasily with the growing opportunities.

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[5] Ziman J., (1994) Prometheus Bound Science in Dynamic Steady State, Cambridge University Press, London, 289pp.

The consequence is that scientists need a new operating paradigm, a new framework which accepts, at least, the reality of modest real growth of resources. While the pressures of knowledge generation and new opportunities were released through growth in the old paradigm, they must be handled by greater selectivity, discipline and priority setting in the new paradigm. This is not to argue that total National expenditure on science and technology has peaked, but rather that it is likely that growth is not sustainable and that we need to learn to live with that fact.

The thesis of this submission is that the practice of Science and thus its funding and sponsorship within a modern and developed country should recognise these limitations but at the same time the multiple role of Science investment. It can contribute through the:

- Building of wealth through the application scientific knowledge in saleable products, hardware, software and managerial approaches; ***Wealth Generation***
- Capture of new scientific and technological knowledge built elsewhere: ***Knowledge reconnaissance***
- Presentation of new and emerging Science and Technology in private and public policy setting: ***Underpinning policy development, public and private sector***
- Building a scientific and technologically literate/sophisticated community through formal and public education: ***Underpinning scientific/technological literacy***
- Solving problems that depend on science and technology for their resolution: ***Solution to problems***, and
- Building new knowledge as a strategic investment to underpin the above; ***Expanding knowledge frontiers***.

Such pluralism maximises the potential value of the National investment on behalf of the community.

Wealth generation

There is no doubt that the generation of wealth through the production of products for sale is important in the National interest. It can strengthen Gross Domestic Product through domestic demand, international trade and competitiveness, employment and regional opportunities. All sectors of the community can benefit from the impact of Science and Technology in the wealth generation process. By and large, this process is seen as the application of existing knowledge for this purpose but can involve innovative linkages across Scientific and Technology disciplines and to other segments of the community, the so-called innovative process. It represents a particular process that is unrelated to but distinct from the knowledge generation process. It requires institutional arrangements, governance and management processes and staffing that is not always identical. If Science is not perceived in its true breadth, then there is a danger of over investment, excessive expectations and non-strategic concerns over the ongoing delivery of these outcomes.

Knowledge reconnaissance

Globally, less than 2% of Science and Technology is derived from Australian investment. Therefore, for such a small country, it can be argued that substantial investment in the reconnaissance of information about new knowledge is in the interest of both the private and public sectors. Major companies will indeed make such investments themselves, but for public policy development and for small and medium-size enterprises it remains strategically important that such information is available as early as possible. The active participation of Australian scientists in international Science is the most important mechanism whereby Australia is made immediately aware of new developments well before they become mainstream and thus on the radar of policy developers and entrepreneurs. The overhead is the support of scientists to take part in Science and international activities is an entry ticket to international developments and forewarning about the emergence of new opportunities.

Policy development

More and more, policy development in the private and public sectors involves scientific and technological considerations, such as with the application of new technologies, or supplementary as underpinnings to policy development. The power of Science is widely accepted in most cases related to respect for the rigour of Science and its capacity to deliver new and exciting opportunities. Yet at the same time, Science alone is often inappropriate for policy development if the policy developers are scientifically ill-informed and/or the scientists incapable of the required dialogue. This is discussed further in Section 3 below. The process of the exchange of knowledge between scientists and policy developers is complex, largely fortuitous and *ad hoc*, and without rules of engagement (for more see Annex 3).

In a society that values the underpinning of policy with factual descriptions of reality and the probabilities of likely risks and opportunities, Science can be used as a component of expert advice to underpin good policy. The degree to which this will be the case will depend on the circumstances. For example, what we know and don’t know, are important components of any policy development issues such as climate change.

Education

The successful adoption of new scientific and technological gadgets, tools of management, etc depends on community acceptance and meeting of societal norms and values. This likelihood of this acceptance can be enhanced or the potential of this can be enhanced through a well-developed public understanding of emerging scientific and technological options. Thus public awareness and understanding is tantamount to the instigation of new directions that will capture public and private support. Failure to accept this means that there is a risk that the most potentially significant innovations coming from Science and Technology may be thwarted by public opinion, biases and objections. Further the instigation of any outcome from Science and Technology requires technically capable and trained personnel. Such training, particularly at senior level, can be strongly enhanced through the existing investment in otherwise research based organisations. Education underpins both this public awareness and ensures a highlight that would that the investment in research itself will be of value.

Today's society is highly dependent on scientific and technical solutions. Yet these often raise questions of public acceptability. Prime examples are in the application of stem cell technology, genetic engineering, nuclear energy, etc. It can be argued that a number of cases, the public debate or rejection of aspects of these technologies has had more to do with public ignorance or lack of awareness of and appropriateness of the technology than their actual applicability. No modern democratic society can operate without a degree of engagement by the population as a whole in the assessment and acceptance of technologies. The most well reasoned and economically viable technology solutions may be worthless if the public is fearful of it or rejects its implications and value though ignorance.

Formal education

The ongoing and strategic involvement of Science and Technology depends on investment in the training of new scientists and that there is a community of schoolteachers, university lecturers, media experts and scientific literature executives. Each has an important role to play in the provision of up-to-date information about emergent Science and Technology and its achievement implies an active participation of scientists in public communication in the media. Such communication is unlikely to occur from scientists funded specifically to provide consultancy work.

Public education

Indeed public funding is required to support the participation of at least some scientists in this important role. The scientific perspective will not always represent a balanced and inclusive evaluation of important issues. Nevertheless it forms an important component of the education process.

Problem solving

Certain issues arise from time to time that demand companies and governments to seek scientific and/or technological solutions. These could be issues such as those that arise in the processing of minerals, the quality control of agricultural production, the reduction of disease and medical costs, the proliferation of the protection of ecosystems, etc. Here the issue is that a definable risk exists and scientific research seeks a solution to the problem.

Science which is currently seen as the most important input to the solution to these problems which is clearly related to the source of wealth generation, the avoidance of cost, the importance of efficiency.

The popular view of the community and governments is that this role can be performed by private sector consultants who apply current knowledge assessed from around the world. But in its broader context this should include proactive scientists who may by virtue of their understanding of the relevant systems, foresee problems before they are manifest, for example, climate change. The energy sector would not have engaged in a major reassessment of its future if it had not being that climate scientists demonstrated that ongoing greenhouse-gas emissions are not sustainable.

Knowledge generation

It is obvious that the application of knowledge, particularly new knowledge that endows a competitive edge in business, and major public-good risks, derives from new knowledge, in which public investment is necessary. Thus knowledge generation is of value itself, but also in that it enables the process of engagement with the wider world of Science, as an entry fee into this wider world, as the basis for the intellectual practice and maintenance of frontier capacity of the scientists themselves who will deliver to both knowledge generation and application.

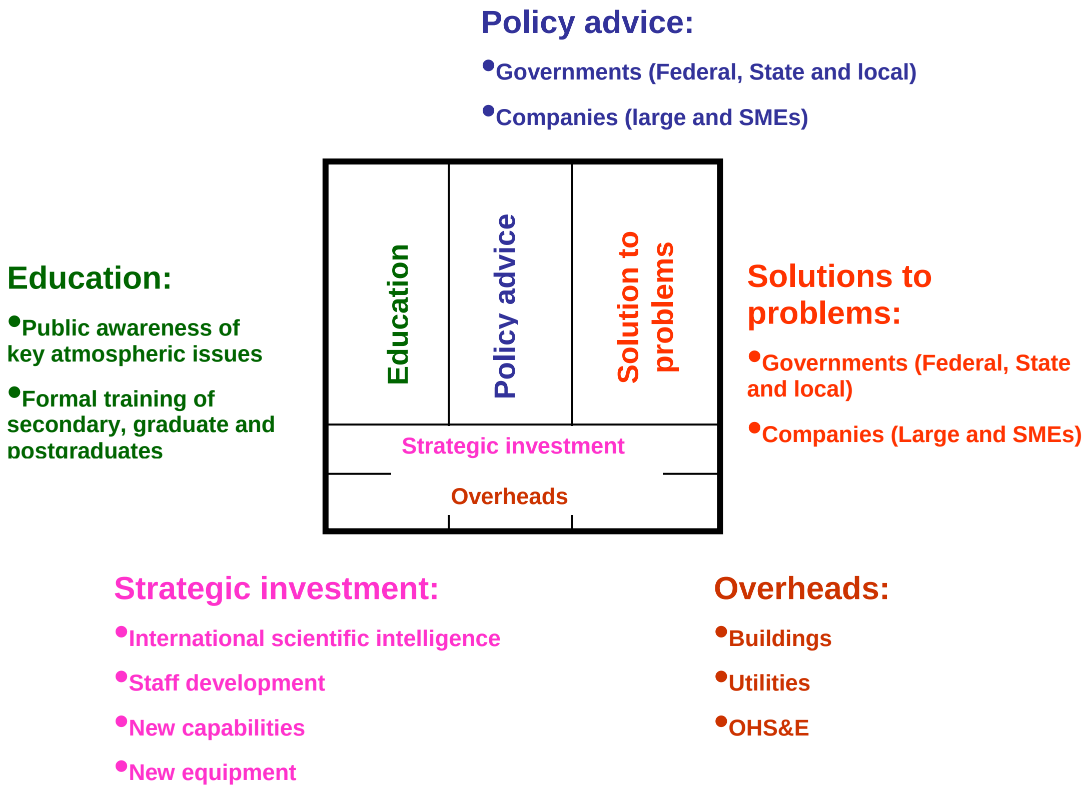

Figure 1: A diagrammatic representation of the pluralistic view of the role of Science in modern Australia. It identifies the decisions that mangers of national research agencies need to make about the allocation of resources across the breadth of this portfolio.

The focus on wealth generation

The argument here is not that investment in Science seeking returns through National wealth generation is not a legitimate process, but rather that either this needs to be considered as a subset of the pluralistic role of Science and the investment process, or that the concept of wealth needs to include such components as public scientist/technological literacy, international awareness, policy sophistication and inclusiveness, etc. This is tantamount to questioning the model that suggest all human aspirations can be fulfilled by building economic wealth- the other outcomes will follow. This is clearly a poor representation of the reality that direct attention needs to be given to all aspirations concurrently. This is the essence of the emerging ethos of “sustainability”.

The institutional arrangements for Science, including the role of public versus private funding depends on what you really wish to achieve. What is the spectrum of outcomes from the overall portfolio that is to be addressed?

The **first key message** of this paper is: Science has delivered enormous benefits to human existence and well being over many centuries. Curiosity and the intent of individual scientists to press the boundaries of scientific knowledge have by and large driven this science. It is unlikely that suddenly, in the twenty first century, the value of this approach to science will disappear. There is a need, in any national science policy to recognise the on-going human value in Mode 1 (see Annex 2), primarily science-driven Science. This remains true today simply because the nature and content of future scientific knowledge is unpredictable. In that respect it is not possible to define the directions by which we get to the inevitable new disciplines and discoveries, other than by a policy of commitment to scientific freedom and unfettered scientific endeavour.

This statement might be interpreted as a conservative call for things to remain the same. On the contrary, we understand why this approach is needed, and we recognise that it is not the only approach. Scientists, science administrators and governments need to make informed judgements as to how much resource should be put into Science of the Mode 1 and Mode 2 type (see Annex 2).

The **second key message** of the paper might well be the corollary. The solution of key issues for human societies will often lie in the application of science through Mode 2 knowledge generation where scientific knowledge is integrated into the company/government/community desires to deliver targeted outcomes. This is no more relevant to the movement of, for example, climate change science from the phase of “blowing the whistle” on the existence and relevance of these changes, to the phase where the science community is intimately involved in the development of realistic solutions. It does not deny the fact that similar threats and opportunities will arise in the future, about which we can not anticipate or know.

We can argue that we don’t wish to not know about the next “ozone depletion” issue, or the next “salination” issue until it is too late. Science needs to be operating in such a way to alert the community to new views of the world, views that will not be generated by the community at large. Equally, the community needs to harness Science in the seeking of solutions to those and other problems.

The **third key message** then is that the community invests in Mode 1, fundamental or basic science because the future is not knowable beyond the predictive powers that new fundamental knowledge gives use. The community invests in this science because such a scientific community delivers a world view that is different to that of economists, lawyers, brick layers, etc. Not necessarily better, or more important, but different and for that reason alone, valuable.

It should be mentioned that investment in research, but particularly in Mode 1 research, inevitably brings with it other important outcomes. This kind of research cannot be undertaken, by definition, without a rigorous and ongoing knowledge of the boundaries of the exiting knowledge base. Given that a single organisation or country does only a small fraction of the totality of knowledge generation, an investment on a local science base acts as a window on the rest of the world's knowledge development. One could actually argue that as long as scientists are talking to and exchanging knowledge with the wider national community, then their existence as a sponsored group in the community might be justified on this 'window to the world of Science" concept alone.

This is therefore an argument for pluralism in our science policy. It suggests that we need two kinds of scientific approach and two types of outcome. It is an argument against the current focus on the delivery of outcomes, particularly economic outcomes. These are important and a national science policy must include this aspect. But it needs not to be at the expense of the important role that "science drive" can also deliver. If one accepts this, then it leads to an alternative way of looking at the conduct of science.

The **fourth key message** is that in the formation of institutions to undertake components of the National research effort, these spectrums of purpose and research approaches (see more in Annex 2) will exist both in the nature of the research performed and in the aspirations and realities of how operating scientists work. For these reasons, the coexistence of institutions that span the spectrums, yet overlap in their approaches is healthy (see Figure 2). Forcing all institutions to serve a common feature of the spectrum is dangerous.

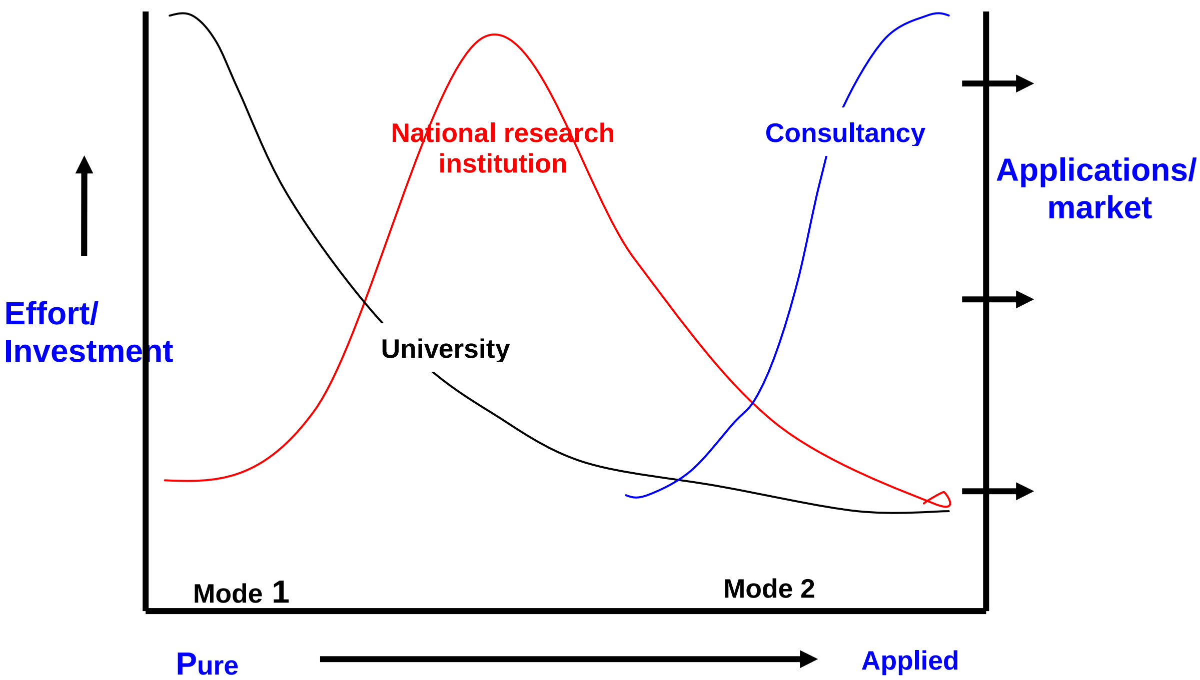

Figure 2: The interconnections of various investments through different institutional structures to the National demand for research across the full spectrum of "pure" and "applied" science.

3. Special case of Science-Policy interface

The comments made here are not directed at any specific government or company or at any specific person or Organisation although they clearly are influenced by the submitter's personal experience in CSIRO. The thrust of this Section is that:

- The Science-Policy interface is a broad and complex issue, questioning one of the roles of Science in modern society
- The methods and purpose of public communication are poorly understood and there is a lack of a shared view of the processes
- This is not a reflection on anyone, but on the stage of human development
- There is a need for rigorous examination of options and processes and through leadership the development of a clearer and accepted way for Science to interact with public awareness and policy development.

The issue of publicly-funded scientists making public comment is viewed here as a subset of the wider issue of the role of Science in policy development. In turn this is part of the wider issue of the role of expert advice in underpinning public policy development. It can be argued that in recent years there have been many examples of policy development characterized by:

- Advice appears to have reflected perceived ideological positions of the policy-developers rather than independence
- Application of expert advice to support that held political industry ideological position rather than to seek opinions spin rather than wisdom.
- Government departmental interference, in good faith, is part of a perceived legislative role to influence advice consistent with perceived objectives.

Fundamentals of the science policy interface

In order to justify the position taken in this paper is necessary to articulate a view of wider issues of how Science interfaces with public and private Policy development (summarised in Figure 3).

The interface of experts with policy development

There are many common characteristics between the interface of Science with policy development and that of the interface of other experts groups within the community and policy makers (e.g. the judiciary, economists, engineers, etc.). These include:

- This is not about the experts making policy but rather providing expert underpinning advice that may ensure that ultimately policy is not flawed because it is ill informed scientifically or technically.
- A degree of intimacy between the policy maker and the experts is necessary to ensure mutual understanding of both the policy issues and the Science. This intimacy means that there is no clearly defined border between Science and Policy, despite attempts to define one. Clearly there numerous links and the Science policy interface is used to reflect this reality. Where's he turns on or ministers clearly step outside of their

respective roles turned tried to be taken the importance of scientific issues there is a problem. No less is the case when scientists try to anticipate the value of emerging science and technology in a broader community perspective. But by and large these limitations are well understood and examples where and responsibilities are exceeded are rare.

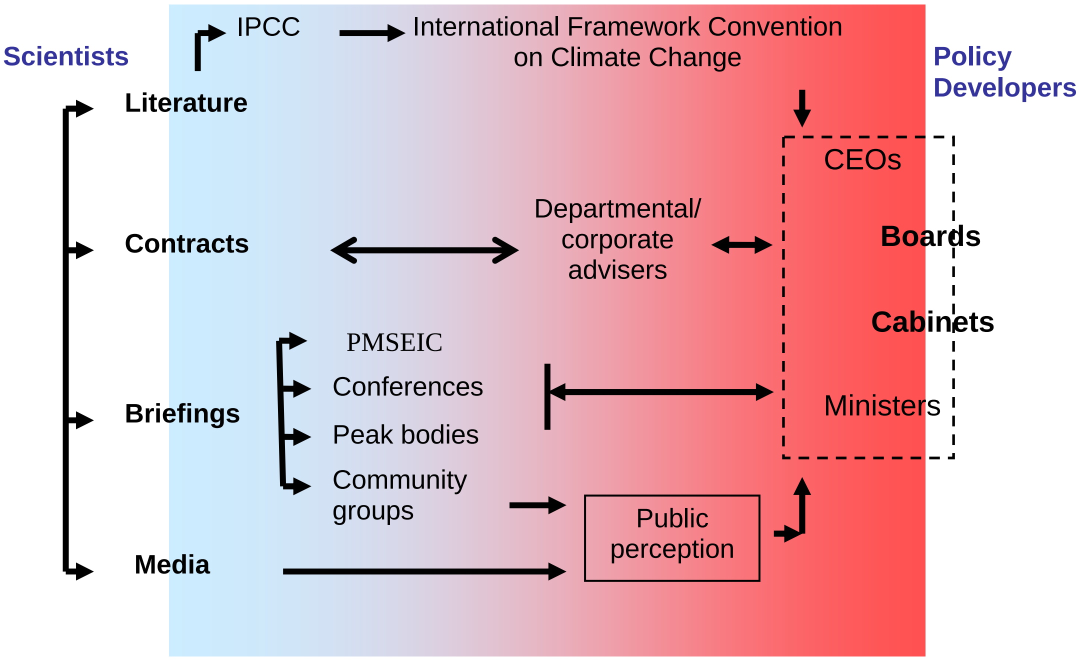

Figure 3: A summary of some of the mechanisms whereby Science influences and supports public and private policy development. The coloured shading represents the fact that there is no hard and fast separation of Science and Policy, but rather an interface, the Science-Policy interface. Note, IPCC refers to the Intergovernmental Panel on Climate Change[6].

- This degree of intimacy entails potential dangers that include:
  - The policy developer may deliberately or inadvertently capture the scientist/expert to deliver a required outcome. The potential for this is maximised where the experts are financially dependent on the policy developer. Significant examples exist where commercial consultants and CSIRO has struggled to have their advice publicly accepted when a difference to existing policy or ideological positions
  - The adviser captures the policy developer. Examples exist where public policy has been captured by strong personalities or via implied threat for example by industry threatening to "move offshore", "make redundancies", etc., that might undermine the electoral popularity of the government or Board.
- At the end of the day processes for the interface are built around mutual respect and acceptance of independence as it is to the wider community benefit.

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[6] Intergovernmental Panel on Climate Change, a specific program of activity established in the late 1980s reflecting the need for the rapidly developing climate-change science to be better interfaced with a rapidly growing demand for policy intervention. His has been a huge experiment in the science-policy interface, one that has, by and large, been very successful.

Mechanisms for science policy interface

Thus, there is no single door through which Science advice is poked for use by public or private policy developers. Indeed the notion of Science generating knowledge that is put on a table (in the literature) for the entrepreneur to pick up, is a Mode 1 perspective of Science and is largely succeeded by a more collaborative and interactive approach by the knowledge generators and the knowledge users. Recognizing the need for Science to be responsive to policy needs, as define by policy makers, this should not exclude proactive provision of advice. For clearly, often non-scientists will be unaware of emerging developments in Science and Technology that may have application, or turn out to be relevant. While the focus of responsiveness has its value, to some extent it is borne out of the overly zealous "accountability" thrust of the late 20th century, and, as with so many things, has its time and place.

This proactive engagement in policy advice, more than responsive engagement, places significant obligations on the scientist to understand where and when such advice might be useful, where it is genuinely for advice and not self promotion, and how such advice will be treated; seen positively or gratuitously. Not all scientists will be sufficiently experienced to make such judgments and institutional monitoring may be necessary.

While is important to recognise the grey area between Science and policy and that the existence of this grey area is a positive rather than negative aspect of the interface is also important to accept that there are no hard and fast mechanisms by which the interface proceeds. Indeed there exists a suite of mechanisms, some of which are described briefly in Table 1 and illustrated pictorially in Figure 3, that make up an diverse and largely *ad hoc* mix. It can be argued that there is a need to retain this diversity of mechanisms but equally a need to examine these approaches to establish both a more wider and shared understanding and acceptance of the mechanisms and identify the strengths and weaknesses of approaches of specific mechanisms for specific purposes (e.g. shareholder-based specific industry companies, government departments both State or Federal, wealth generation, or public good, etc.).

The mechanisms described briefly in Table 1 are but selected examples, more to make the point that various mechanisms exist rather than to be comprehensive, and to show that each has its strengths and weaknesses and each demands from the policy maker and the scientist different approaches.

Mechanism	Description	Potential Strengths	Potential Weaknesses
Formal assessment processes	A processes established whereby an area of developing Science is periodically reassessed and presented in a policy relevant way	The independence of the Science community and its culture of peer review is acknowledged. The assessment is to some extent targeted around recognise policy issues	Somewhat cumbersome and time-consuming. Reflective of the user's' perception of priority, which may or may not be best
Response to call for comment on white papers	Policy development presented in draft papers and scientists responding to incorporate important aspects related to scientific and technical issues	Scientists and technologists are generally free to respond in an open and fearless way to this call advice	Reflective of the user's' perception of priority, which may or may not be best Can be politically influenced by any involved departments
PMSEIC/PMSEC, etc.	The Chief scientist, Prime Minister or others identify issues of concern and seek scientific and technical input	Addresses perceived policy issues at least from government's point of view where there is agreed of fearlessness on the part of the scientists and technologists	Will be mostly user driven and thus not necessarily forward-looking. Can be politically influenced by any involved departments
Contracts	Government department of company board commissions the contract concerning a perceived scientific or technical issue	Targeted and reflective of policy developers views of what is needed for policy development developer	Extremely vulnerable to clients interference in final presentation of material. A growing problem
Briefings	A company board, industry body, government department, seeks scientific and technical briefing on a specific matter	The scientists and technologists are free to express scientific and technical views relating to the specified topic	To work well requires significant time to allow for a briefing and then interaction between the user and provider
Public awareness	Scientific materials are provided to the media for public circulation	Contribution can be made to broader communication and awareness building related to emerging issues not necessarily in the mainstream of policy development. Underpins democratic engagement in policy development	Demands time from the scientist which maybe in conflict with other priorities and demands in the workplace. The scientist can be too focused and fail to recognise bigger picture issues. Media tends to sensationalise issues must regards to Riga

Table 1: Some of the myriad of mechanisms that exist for interfacing Science with policy development. This is illustrative rather than complete, reflecting the need for more rigour around the processes so that they maximise the value of investment in Science from the policy point of view.

4. Comments on the role and nature of CRCs

One feature of the Prime Minister's Backing Australia's Ability program is its further support for the national Cooperative Research Centre (CRC) program. This raises a number of questions in the mind of the author. Again it is not that the author is convinced or dogmatic about his impression of this program, but rather that a systematic review and assessment of its value *vis a vis* other science-innovation funding arrangements has not occurred. The author contends that it has be the successful "selling" of the CRC program rather than hard facts on its successes that have influenced senior political views in both the current Government ranks and the Opposition parties.

CRCs are indeed structures that reflect the shift toward Mode 2 knowledge generation. That is, their strength lies in the concept of drawing together heterogeneous teams of players to deliver well defined outcomes through scientific knowledge. In this regard they certainly do have a purpose. The questions in the author's mind relate to whether these structures are always the best solution for particular case of knowledge generation and/or application and whether, the administrative "straight jacket" defined for the operation of these units is in itself counter productive.

In the first instance, as has been argued above, not all scientific research should be driven by the knowledge generation cycle alone, leaving open the option for some component of a National investment in scientific research to operate in the Mode 1 form. Thus whenever national resources are shifted, or perceived to be shifted from Mode 1 to Mode 2 knowledge generation, there will be, and should be questions asked about whether the balance is "right".

Recognising that the CRC program was a deliberate attempt to capture knowledge for application, then we need to look at how well that has taken place.

CRCs, as with all Mode 2 science operations, have the potential to absorb huge quantities of resources in the networking required bridging the gaps between the players. The issue of inter-cultural barriers to team building in the application of science, particularly in policy development cannot be discussed here, but is a very important issue in dealing with real worlds problems and opportunities. However, whilst the heterogeneous nature of the mix of players brought together in the Mode 2 operations are on the one hand their strength, they are not without problems. In my experience, the formation of these teams takes literally hundreds of hours of discussion and negotiation before the teams are in a position to submit and defend a submission for a new CRC.

Then there are the actual start-up issues: the gathering of staff, the setting up of new laboratories and offices, the learning of new skills and the employment of support staff. These demands can eat well into the first 2 years of operation of the CRC, again impacting on the efficiency of use of scientist's time to do Science. This time often takes some of our best scientists away from research, significantly reducing their research outputs during this time.

Then, CRCs have a nominal lifetime of seven years. Again in my experience, well before the lifetime of the CRCs is up, staff start to move in the interest of ensuring ongoing employment.

There has not been a rigorous assessment of these impacts, and it is likely that it would vary significant between CRCs in any case. The earlier evaluation of the CRC program was in my view superficial and next to valueless. My rough estimate is that these inefficiencies (proposal planning, start-up costs and termination costs), probably account for effective cost of at least one year's of resources (approximately 14% of the investment over a seven year life of a CRC).

These units are, by and large, operations of order $10 million annual turnover, significantly smaller that the average size of a program within a CSIRO Division. Yet these units are expected, under the rules of operation, to sustain a Board of management (sometimes with a separate Advisory Committee). They usually support a senior program manager, finance manager and often commercial mangers and promotions/publicity officers. These are overheads usually shared by whole Divisions or even shared across Division (in the case of Advisory Committee) in CSIRO. The overheads are substantially greater in this regard. But then, many of the scientists involved in the CRC come from other institutions. So they find that they are subjected to annual performance reviews in at least two Organisations, and the demand for preparation for these such as preparing separate annual reports, being interviewed for performance assessment by both parent Organisation, and so on. The inefficiencies are significant and frustrating for many scientists.

I repeat. It is not that the author knows for sure that these factors lead to unacceptable levels of efficiency. Nor is it certain that these are not legitimate costs of some forms of Mode 2 knowledge generation. But, rather, that these questions are not being raised. There is a perception that these institutions have been highly successful and should form the basis of a substantial part of the future policy for science in Australia. The preliminary evidence suggests that such Organisations are probably a factor of 50% at least less efficient than existing Organisations in which careers can be fostered. Indeed, even the issue of delivery of outcomes is at question. Where is the evidence of real performance of CRCs? An analysis, for example of the number of spin-off companies generated per dollar of CRC funding invested compared to that of per dollar of CSIRO finding shows that the more conventional Organisation outperforms the CRC program, even though CSIRO often delivers a wider range of outcomes to the community than the CRC program. We need to be much better informed on what the real value of this program. We need to move from the emotive hype that has been generated about their success, and to dogma that suggests Mode 2 knowledge generation is always appropriate. We need to use careful analysis on a case by case basis as to what are the appropriate institutional forms to deliver desired outcomes. Such a review is well over due.

One might of course ask why has the CRC attracted significant support. Again I can not be sure, but I suspect that when the University Sector was so significantly decimated as it has been in recent years, that Sector of the research/academic teaching community saw CRCs as the only bright light, to be the only way that they could build funding and maintain research activities.

Annex 1: Brief Curriculum Vitae for author of this submission

Dr Graeme I Pearman AM, FAA, ATSE, FRoySocVic, BSc(Hon), PhD

Dr Graeme Pearman was trained as a biologist at the University of Western Australia where he. He joined CSIRO, in 1971 where he was Chief of Atmospheric Research, 1992–2002. He contributed over 150 scientific journal papers primarily on aspects of the global carbon budget. In 2004 he left CSIRO to run his own consultancy company. He is currently Senior Honorary Research Fellow, Monash University and contacted to the University to establish a new Monash Sustainability Science Institute.

Pearman was elected to Fellowship of the Australian Academy of Science in 1988, Fellowship of the Royal Society of Victoria in 1997 and Fellowship of the Australian Academy of Technological Sciences and Engineering, in 2005. He was awarded the CSIRO Medal for outstanding achievement/leadership in research, 1988, a United Nation's Environment Program Global 500 Award in 1989, Australian Medal of the Order of Australia in 1999 and a Federation Medal in 2003. He was a finalist in Prime Minister's Environmentalist of the Year in 2002 and Brodie-Hall lecturer for 2003.

He is Program Leader for a study of an *Australia 21* project on Australia's energy futures. He has recently completed a study for the Victorian Government on how deep cuts might be achieved in the greenhouse-gas emissions whilst maintaining strong economic growth, using the emerging principles of sustainability science.

Examples of his memberships are: *Current:* Chair, START International (Washington) System for Analysis, Research and Training; Member, Advisory Bodies of WWF and Environment Business Australia; Chair, Antarctic Research Assessment Committee (Physical Sciences) of the Australian Antarctic Division; Member, Review Panel for the International Human Dimensions Programme; Member, Australian Climate Group.
Past: Past Co-Chairman and member, Science Advisory Group for the Asia Pacific Network for global change research (Kobi); Past Deputy Chair, ICSU Committee for Strategic Planning and Review (Paris); Member, National Greenhouse Science Advisory Committee; President, Australia Meteorological and Oceanographic Society; Chair and member, Board of *Greenfleet Australia*; Chairman, Joint Australian Academies Committee for Sustainability; Chair, National Committee for Sustainability (AAS).

His current interests and activities include: energy futures; sustainability and sustainability science; scientific capacity building; public communication of science; and the role of science in modern societies.

Annex 2: Some considerations of the nature and conduct of Science

In assessing the role of Science in modern societies, and in particular publicly funded Science, it is necessary to understand the characteristics of Science that both underpins outcomes and methodologies and delivers expertise and advice that is of value.

For the purpose of this discussion, Science is considered to consist of two highly integrated but nevertheless different processes, the production of knowledge on the one hand, and its application on the other (Figure A2.1). Scientists in the former mode operate on the basis of awareness of the existing knowledge base, the construction of hypotheses to test advances of the knowledge, the concept of experiments and/or rational deduction and the testing of the outcomes in the peer reviewed literature. Despite external views of this process, by and large it is highly competitive with scientists competing to provide the next advances in the context of global knowledge system. Reward for scientists operating this mode relates to the provision of infrastructure to advance their work, satisfaction in competing internationally and salary, often in that order.

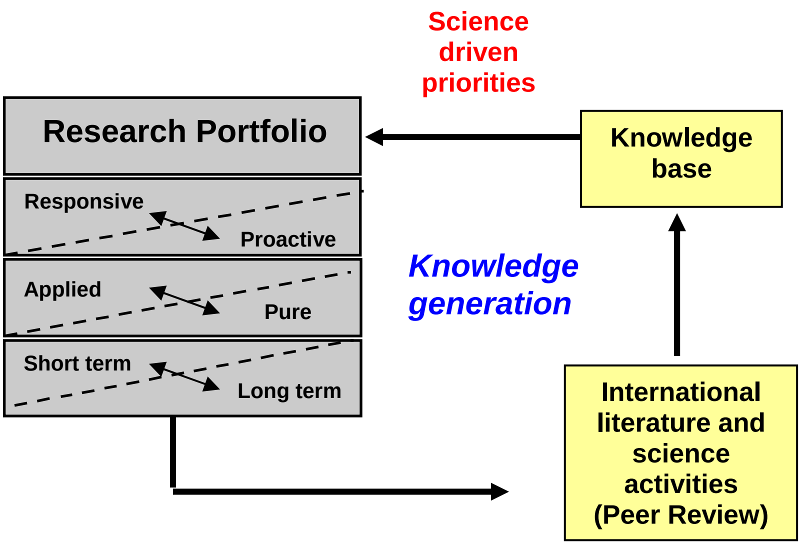

Figure A2.1: The knowledge generation cycle of scientific endeavour.

In the setting of priorities around hypothesis and project development, there is a range of considerations that provides complexity. First research projects may be designed with scientific intend as the major driver (pro-active) or with external intent and demands as the major driver (responsive). Some work will anticipate results on timescales of months and others will be long-term decades.

The mode of assessment of performance in this domain will be largely around number and quality of publishing in peer reviewed journals, the development of national international status membership of academies etc.

Funding is more likely to be public investment and/or endowments by individuals.

The second mode of operation is that of knowledge application (Figure A2.2.). Here scientists are more directly driven by external views of the hypotheses/opportunities to be assessed, that is, more responsive.

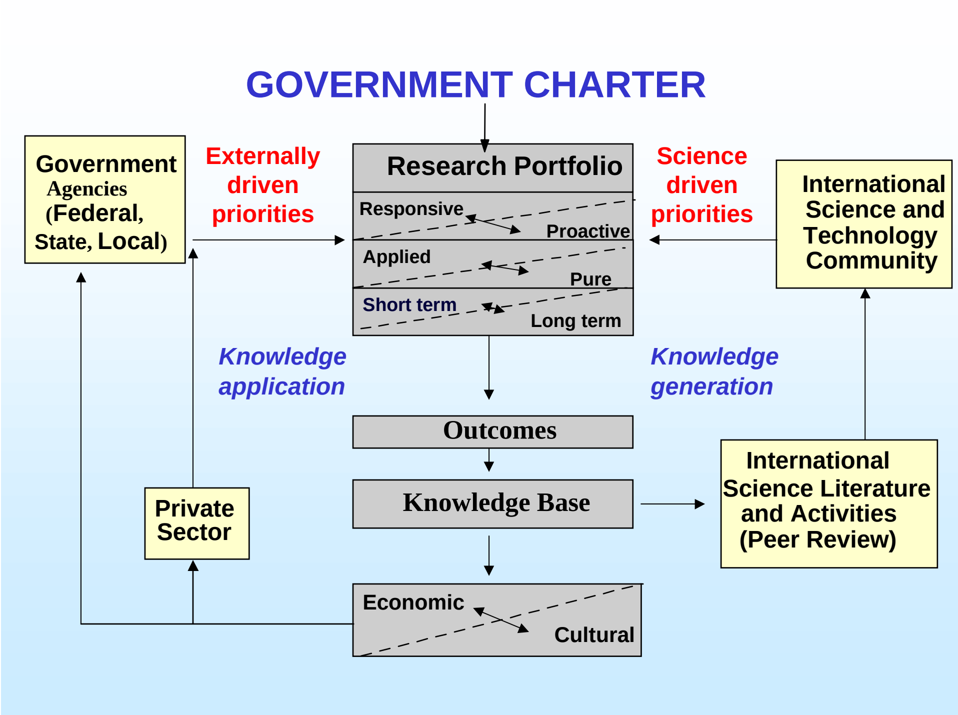

Figure A2.2: The combine, knowledge generation and application cycles of Science.

Performance is likely to be assessed in terms of delivering outcomes on time, the production of patents, intellectual property rights and the contribution to practical achievements such as wealth generation. Such research, because of the sponsorship is more likely to be short-term and incremental rather than strategic. The sponsors will be both the private sector and the public sector and the mode of engagement will be often through contracts. Here there is a significant overlap the role of private consultants and universities or publicly funded agencies.

In reality many scientists practice Science in a mixture of both these modes. Having managed and for interacted with hundreds of professional scientists, it is a minority that deliberately choose to operate in one or the other of these modes. Most find either, funding and the evolving views of the role of Science and its acceptability require that they meet the criteria of responsiveness. Alternatively they find that their responsibility as scientists drives a wish to contribute to the greater good by making the outcomes of their Science more practical.

It is not that one of these or other of these approaches is more or less valuable, rather that Science contributes through the application of both approaches and one cannot operate in a vacuum from the other. The corollary of this is that investment in any one of these applications at the exclusion of the other is counterproductive. On the one hand one can lead to loss of context in terms of the real-world needs and the other can lead to a disconnect from the strategic and policy value of new knowledge.

Some very serious scientists believe that these processes are sufficiently independent that institutional arrangements can be made in which knowledge generation is separated from those investing in knowledge application. For example some university scientists have argued that universities should be provided with the role of building knowledge while CSIRO be charged with the role of applying knowledge. When this issue was raised recently, Dr John Stocker previously the CEO of CSIRO correctly pointed out the reality that good scientists are challenged and motivated by the advancement of knowledge. He argued that the staffing of research institutions designed to focus on application will only return quality outcomes if it attracts top-quality scientists who can work in a balance between knowledge generation and knowledge application. I strongly endorse this view. The idea that these two modes of Science can be compartmentalised into say universities and CSIRO, fails to recognise this point. There is also a tendency especially among scientists to see knowledge generation is somehow more “pure” than application. Yet in my own experience, scientists good at one aspect will generally be good at the other first because of their personal knowledge and networks, and second because both benefit from intellectual capacity.

This argument suggests that often highly innovative and strategic applications will rarely arise from consultancies unless they are strongly underpinned by knowledge generation or externally through cross-institutional collaboration.

Some twenty years ago, the Chief of the CSIRO Division of Atmospheric research, Dr C B Priestley, nearing the end of his career, was prompted to write a brief paper[7] on the role of strategically based scientific research in the context of applications. He was in fact addressing the age-old debate about the balance of “pure” and “applied” research, their separate value and their interdependence. Such a debate, albeit somewhat more sophisticated, continues today. Indeed, it might be regarded as more important than ever to have the debate and to share a reasonably common view on this issue, as the role of science and technology is greater today than ever before in determining the opportunities and futures of all nations.

Some scientists take the extreme view that without commitment (assumed to be by the State on behalf of the community who pay their taxes) to the sponsorship of free ranging, self directed and elite science, Science itself can not function. That the real benefits of Science can not be predicted and that it is counterproductive to target or interfere with the directions of scientific endeavour. This view, partially reflection the closed academic community of science education, and to some extent its globally shared views of itself, hardly reflect the real objectives of a strategically based research Organisation such as CSIRO.

It is not that their views hold no value, but that they are such a narrow, often closed minded picture of the complexity of the real world. If nothing else they are very arrogant. Science, like art and to some extent sport, does derive community sponsorship to practice with remarkable freedom to encourage invention and originality that flow from this freedom. It is an investment by the community at large in the special talents of a few. But like art, at least, the modern world questions this

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[7] [1] C H B Priestley

investment more today than ever before. By and large, this questioning comes both from a relatively poorly informed public that may misunderstand the nature of Science and its potential value, and from the ideologically based rationalists with equally poorly developed understanding of the potential of Science, its pluralistic outcomes and its delivery modes.

It is the later sector of the community that is potentially the most destructive. Like idealism in any sphere of human endeavour, it has its attractions in its simplicity. It attracts its adherents often because it offers simple solutions. Today the rationalists have sway. They have convinced the ruling elite and leadership and strategic open thinking is on the wane.

This Annex attempts to provide a summary of the way science is conducted, to generate knowledge, and them how that knowledge can be applied.

Traditional science was practiced to generate new knowledge. It was and is self regulating and based on rigorous procedures and mores. Scientists are obligated to be learned in terms of the existing knowledge base, generally represented by the present (and more and more electronic) formal scientific publications. These publications themselves represent a cornerstone of the scientific process in that material is published only after rigorous peer review to maximise that chances that methodologies and interpretation of results are sound. Thus the published literature begets new questions that drive the formulation of new hypotheses. Experimentation and inductive and deductive argument turns observations of the world into acceptance of hypotheses or otherwise, thus, if acceptable to the peer review process, enter the literature as the new knowledge.

The important elements of the *knowledge generation* cycle in Figure 1 are universal to the scientific process and reflect the methodology that represent scientific technique and the value of science as an approach to *knowledge generation* compared with any other approach. But it is also true that while this rigidity of approach exits, the options in terms of it implementation are enormous. In the first instance, a research portfolio of an individual scientist or of a scientific institution will need to address issues such as proactivity, relevance, time span and anticipated outcomes[6].

Proactivity refers to the level of independence of the researcher or institution in determining the hypotheses to be tested, compared with responsive hypothesis setting where the hypotheses are directed by the views of others as to what needs to be tested. Relevance has to do with the question raised at the beginning of this Annex. That is, do the hypotheses need to based on output or outcomes of the research that will have relevance to the intentions or activities of others, or is it entirely devoted to the expansion of knowledge for knowledge sake? In this sense, research outputs may deliver outcomes for a wide spectrum of community sectors including the betterment of social development, cultural perspectives and environmental quality, as well as underpinning economic growth and strength. Hypotheses can be purposefully framed to address issues likely to be solvable in the short term or longer term. The scientist has the option of setting such goals.

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[6] Outcome here refers to the impact of the *knowledge generation* rather than the knowledge generated which in this document is regarded as an output of the research.

The classic view of Science and its role in delivering outcomes to the community is simple: free ranging, unencumbered pursuit of knowledge, will generate new knowledge which in itself is unpredictable. Its value and in a sense of its legitimacy is based on it being tested though the peer review process of the institution of Science itself, and that the knowledge is open to the wider community for application. This mode of knowledge generation and application is referred to here as Mode 1 (Figure A2.3).

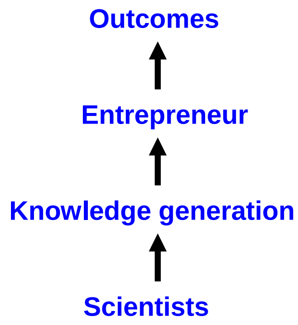

Figure A2.3: Mode 1 knowledge generation.

The term "pure" in evaluating the science portfolio refers to the degree of external influence, particularly non-scientific influence on the hypothesis setting. This external influence is of course, based on expectations that the science will deliver outcomes related to one sector of other of the community, in ether cultural or economic benefits.

It is more useful to consider this as a separate cycle of *knowledge application* (see Figure A2.2).

Here the linkage to external priorities that influence scientific priorities is identified related to both government driven policy needs and private sector needs. Both may relate to the solution of particular problems, assistance with the setting of policy or educational needs. The difference is largely the anticipation of outcomes rather than knowledge itself (outputs). In the case of the CSIRO, then a Government Charter predetermines that this is the nature of the Organisation as it is expected to deliver outcomes for Australia through strategic research, that is research which is responsive to, in terms of the hypotheses to be tested, anticipated outcomes.

The interaction between the *knowledge generation* and *knowledge application* cycles is complex. Indeed, for much of history it has been very loose, expect in those areas where the scientific institutions themselves have been very much at the applied end of the research spectrum (more on that later). But in recent years, several factors have lead to an intensification of attention to the mode of this interaction. In part this has come about by the desire to account for funds expended on research in anticipation of community outcomes. This accountability seeks more formal evaluation of both the methods by which the *knowledge generation* science is responsive to externally perceived objectives based on anticipated outcomes. In part it related to the need for accountability and the relating of "scientific" success. To community uptake, application of evolution based on the research outcomes.

The emphasis on outcomes and the accountability of science to these outcomes has a number of consequences with respect to how science itself practiced and perhaps to the conduct of Science itself. It has been argued that as late as the 1980s, there was a global movement away from, the Mode 1 model for the generation of knowledge to the Mode 2[7] model (Figure A2.4).

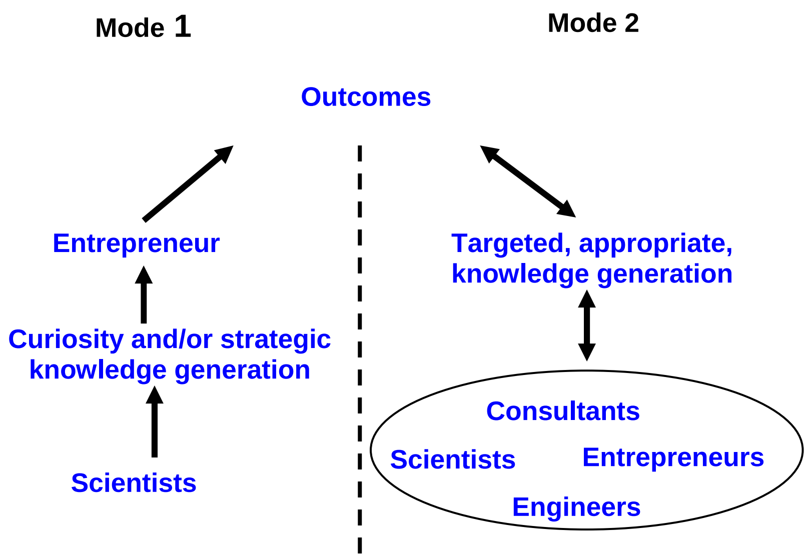

Figure A2.4: Mode 2 knowledge generation.

The essence of this is that scientists partake in teams that together decide on the nature of the science to be performed and the kinds of outcomes to be obtained from the science conducted. There is little doubt that this approach is driven by the accountability objective. Few would question the motive itself, but it does bring into doubt a number of issues concerning the impact of the approach if it becomes the dominant if not the prime mode of knowledge generation.

Forming teams of Mode 2 knowledge generation

Forming teams to address key issues for society, particularly issues of environmental change, must involve interrelations between the scientists, policy developers in governments and industry (enterprise). Indeed, it must of course also involve the public.

It is dangerous to think that this is easy. What is actually involved in the mixing of cultures. For example, those who develop policy (so-called policy makers) such bureaucrats in State and Federal government departments come to the table with very different formal training (often no science training), different worldviews and clearly different responsibilities. If you ask these people what they think of scientists and science, they will generally say that they are focused and very specific about what they do (in contrast to the wider views required in whose to win political support for change). As a result, policy-makers see scientists as not worldly, as naive when it comes to the process of policy making, and often over-valuing the role of Science.

[7] The terminology of Mode 1 and Mode 2 knowledge generation is based on the concepts as defined and discussed by….

By contrast, scientists see policy makers as misunderstanding science, its rules of practise and norms. They complain that policy-makers too often see Science as an immediate tool, understanding science to be a reservoir of knowledge to be turned on in the solution of problems on demand, rather than needed to generate knowledge with of course also has time scales of decade rather than day, months or years, the times scales that dominate policy development.

	Mode 1	Mode 2
Setting of problems	Largely academic In interest of disciplinary community	In the context of application, social and economic Problems defined in a specific and localized context
Nature	Disciplinary Cognitive Entrenched	Trans-disciplinary Temporary and heterogeneous practitioners
Organisational	Hierarchical Tends to preserve its form	Heterarchical Transient
Accountability	Internal community	Socially accountable Reflexive
Quality control	Peer review	Peer review plus Multidimensional

Figure A2.5. Characteristics of the practise of Mode 1 and Mode 2 Science.

There is little doubt that it does focus the mind of the scientist on research targets that are more directly related to community perceptions, not scientist perceptions of needs. And these are often fundamentally different. It does mean that the scientific outcomes are likely to be expressed in terms of the idiom/culture of the “client” or application area, and that in itself is of value.

In particular areas of Science, this movement to Mode 2, is probably important for community outcomes. For example in the area of global environmental change, traditional earth science conducted by natural scientists have identified through observation, and leads to understanding of through process studies and integrative modelling, of many issues of global environmental change. The science suggests that many of these changes are not sustainable. This “doomsaying” by scientists has been fundamental to the identification of key issues in global and regional change that need attention. Such issues have been stratospheric ozone depletion, the loss of biodiversity and the greenhouse effect as global issues, and more regionally, issues such as large-scale salination of soils.

The strength of the scientific arguments has been such that by and large, the community is seeking solutions. Indeed, the community is seeking guidance as to how to make the transition from where we are to where we need to be where human activities do not jeopardise the opportunities of future generations of people. That is, the transition to sustainability. The point is that the identification of these issues arose out of Science conducted primarily in Mode 1 style. But now, in order to identify scientifically and technologically sound solutions that are compatible with the realities of political and real-world constraints, then it is most likely that we now need new work based on the Mode 2 approach to deliver these much targeted outcomes.