What would a 'scientifically engaged Australia' look like?

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DECLARATION

This thesis contains no material that has been accepted for the award of any other degree or diploma in any university. To the best of the author's knowledge and belief it contains no material previously published or written by another person, except where reference is made in the text.

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ABSTRACT

In 2010 the Australian Federal Government released the landmark report *Inspiring Australia* which described the first national strategy for engagement with the sciences, and aimed to create a ‘scientifically engaged Australia’.

This study investigates what might be meant by a ‘scientifically engaged Australia’ by creating a snapshot picture of the current Australian science communication landscape: its priorities, its limitations and its key players’ envisioned recommendations for future activity. It draws on several sources of data to create this picture: academic and practitioner literature regarding the emerging concept of ‘public engagement’; literature and case studies that discuss the appropriate place for deficit model and one-way approaches to science communication; the *Inspiring Australia* report itself and other government policy documents; and a series of interviews with top level public figures in Australian science policy and advocacy.

A central finding of this study is the absence of a universal and unambiguous definition of public engagement. In addition, in contrast to trends within much of the scholarly literature, the study highlights the persistence of one-way methods and to a lesser degree the deficit model in practice. The ongoing use and relevance of one-way communication is evident; it remains a popular, albeit often default, choice in practice and is seen as ideal for the communication of fixed messages. Science communication in Australia remains, for the foreseeable future, dominated by one-way methods, in particular in the use of traditional and social media. In this respect, a scientifically engaged Australia would seem to be one in which a great deal of one-way communication takes place, supplemented by small moves towards dialogical or participatory communication.

Finally, this study highlights two dominant motivations behind the call for a ‘scientifically engaged Australia’. Much high level discourse on this topic is characterised by governments’ desire to safeguard future investment in science and to bolster a dwindling economy, so in this sense economic pragmatism drives much of the science communication agenda. To a lesser degree, a desire to foster science appreciation within society is also a driver. It is apparent that the nation’s science agenda is influenced by the increasing politicising of science, and the communication of it.

TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

CHAPTER 1 – INTRODUCTION AND BACKGROUND

In 2010 the Australian Commonwealth Government launched its 'Inspiring Australia' program, described as 'A national strategy for engagement with the sciences'. It was the first national government-level program specifically designed and established to further the aims of science communication, and was considered long overdue by many in the science communication community. Significantly, Inspiring Australia's emphasis on 'science engagement' reflected a change in focus for science communicators, away from earlier programs in Australia and overseas that were intended to promote public understanding of science, science literacy or science education. Instead, the term 'science engagement' signalled greater interest in a more democratic model of science communication, theoretically involving two-way communication (dialogue) between scientists and everyone else, and the recognition of multiple forms of scientific expertise and experience. This shift in science communication policy reflected a shift in science communication research, notably including scholarship from the influential UK academic community, and so Inspiring Australia is generally recognised as conforming to the appropriate language and ambitions of this time.

However, despite its extensive use in recent years, the term 'science engagement' is poorly defined in the literature, and indeed has meant quite different things to different authors and institutions. Even within the Inspiring Australia program, though it is described as a 'national strategy for engagement with the sciences', the terminology lacks clarity and therefore diminishes its usefulness and potential impact. The absence of a universal, unambiguous definition of 'engagement' provide the basis for this analysis and research project.

The research project's aim is to explore what 'a scientifically engaged Australia' might look like, through an examination and analysis of the scholarly literature, the policy literature, case studies from the practical end of science communication, and also interviews with key leaders and practitioners in the Australian science policy and science communication communities.

The history and evolution of science communication principles provides an essential background in understanding and contextualising the current role and practices of science communication. Accordingly, before embarking on the analytical chapters, the following discussion presents an historical narrative of the evolution of science communication theory, principles and practices as discussed in the academic literature, to give context to the rest of the broader analysis presented in this thesis.

Historically science was conducted by comparatively privileged people as curiosity-led pursuits funded by personal income (Russell, 1932). In recent history science is commonly carried out in universities and government organisations supported by public funds. As such, the public has a legitimate interest in what research priorities are pursued and the results and applications that emerge from them (Dickson, 2004). There are some scientists who still hold the opinion that they should not be required to communicate their research with the public, with scientists stating that instead the public 'should just let us get on with the job' (Stocklmayer, Gore, & Bryant, 2001, p. xii). Others, including governments and science communicators, believe that it is not only in the public's interest to be actively involved in furthering their understanding of science, but also their right to know where, how, and on what, public money is being spent (Stocklmayer, et al., 2001).

The Public Understanding of Science

The formalisation of science communication as a discipline and the establishment of the Public Understanding of Science (PUS) movement was in response to the 1985 Royal Society report called the 'The Public Understanding of Science' (Gregory & Miller, 2000; Watermeyer, 2012). This report identified a crisis in public trust and understanding of science by the UK public. Turney (2002) reflects on this time, stating that the Royal Society report

> was the product of a time when the scientific community feared public indifference more than animosity. There were no votes on basic research, and funding was shrinking – or at least static. …[it was felt that a] better-informed public would be more inclined to support science, and the technologies it helps generate. And increasing the public understanding of science would be good for recruiting future researchers, and good for the economy (p. 1).

The PUS movement had sought to remedy this distrust and generate an understanding and appreciation of science within the public by enhancing the public's understanding of science. The Royal Society report identified that there were

> numerous advantages to be gained from the greater levels of public understanding of science – ranging from more informed personal decision-making to greater national prosperity – and concluded that 'everyone needed some understanding of science.' The scientific community was urged to learn how to instruct and inform the public and to regard such communication as an unavoidable duty (J. Thomas, 1997, p. 86).

The Royal Society report led to the establishment of the Committee on the Public Understanding of Science (COPUS), the first of its kind, whose aim was to interpret and communicate scientific advances to the public, with the mission to increase the UK public's scientific literacy through a cultural change in the attitudes of scientists to outreach activities (Turney, 2002). The recommendations from the Bodmer report state that scientists have a duty to communicate the benefits of their science to the public, in the belief that in turn this would produce benefits for all by creating a more 'scientifically literate' public; a public that would be more supportive of scientific research and more enthusiastic and accepting of technological developments (Sturgis & Allum, 2004; The Royal Society, 1985).

In the PUS tradition, science literacy is not only the ability to read and write about scientific concepts, it is the ability to understand, adapt and apply a variety of science concepts or phenomena (G. Thomas & Durant, 1987). Shen (1975), cited by Miller (1998), provides a comprehensive definition of scientific literacy as a working functional form of literacy; called civic scientific literacy. Civic scientific literacy is a desirable outcome for the population in order to assist them to uphold their civic democratic duties such as voting on matters with a scientific basis, the ability to cope with the increased role that science and technology have in modern living, and being able to adapt to technological change (J. D. Miller, 1998; Sturgis & Allum, 2004).

The desirable outcomes of civic scientific literacy have been articulated as some level of understanding of the impact of science and technology on individuals and on society, and an understanding of the process or nature of scientific inquiry. Other outcomes include a vocabulary of basic scientific constructs sufficient to read competing views in a newspaper or a magazine, the capacity to use scientific knowledge to identify questions and to draw evidence-based conclusions in order to help make decisions about the natural world and the changes made to it through human activity, and the literacy necessary for responsible citizenship (Gregory & Miller, 2000; Holbrook & Rannikmae, 2007; Medved & Oatley, 2000; Sturgis & Allum, 2004; G. Thomas & Durant, 1987).

Achieving civic scientific literacy is an attractive goal as it is based on the belief that people who are scientifically literate may both be more active and more effective citizens, the quality of their personal and working lives will be enriched, and they will no longer be mystified or oppressed (G. Thomas & Durant, 1987). Added appeal in achieving this relates to the concern that modern societies will face a shortfall of sufficiently scientifically literate people to maintain the current rate of technological progress. Achieving a scientifically literate citizenry is important for a variety of purposes, such as democratic functions or building personal capacity to operate technological equipment, which both supports current research and encourages future generations into science based careers (Dickson, 2003a, 2005).

Thomas and Durant's early description of the relationship between the public and science highlights the complexities surrounding the public's scientific literacy. The authors argue that

> [w]hat has gone wrong in the attempt to define the component parts of scientific literacy...is that we have come up with many relevant attributes but somehow missed the heart of the matter, which is the way in which ordinary people relate to the world of science. To be scientifically literate is not to be an expert in anything particular, but rather to be able to deal effectively with matters scientific as they arise in the course of life; it is to be able to cope with science in a way that is both respectful of scientists' legitimate expertise and wary of their many fallibilities and weaknesses; it is to be able to recognise science for what it is, and thus make discerning judgements about its personal and social relevance (G. Thomas & Durant, 1987, p. 13).

The authors present one of the most comprehensive descriptions of the idea of science literacy through the their nine arguments in support of promoting the public's understanding of science, based on a synthesis of the how other scholars of this time defined scientific literacy. The following list provides a comprehensive description of potential benefits based largely on this work by Thomas and Durant (1987):

1. Benefits to Science – Is the belief that public support for science depends upon at least a minimal level of public awareness of the processes and products of scientific research.
2. Benefits to National Economies – Describes the relationship between a scientifically informed public and economic wealth, national competitiveness and the impact of skill shortages. The economic imperative is often the main argument in support of a better scientifically educated public (Stocklmayer, 2001).
3. Benefits to National Power and Influence – Is in response to the post war era and the need for more scientists and engineers to not only sustain expanding civil and military industries, but also to help spread influence to the rest of the world in order to maintain a position of intellectual and ideological leadership. This motivation encapsulates the comment made by Sir Frances Bacon 'knowledge is power' (Dickson, 2005).
4. Benefits to Individuals – Responds to the belief that more knowledgeable citizens are able to negotiate their way more effectively through the social world; in that they are better equipped to make decisions about diet, health-care, personal safety, and a wide range of consumer choices.
5. Benefits to Democratic Government – Is in response to concerns that a more informed citizenry would be able to more effectively participate in policy and political decision making (Dickson, 2003). The 1985 Royal Society report put forward a slightly different perspective as the authors state that 'wider understanding of the scientific aspects of a given issue will not automatically lead to a consensus about the best answer, but rather it will at least lead to more informed, and therefore better, decision-making' (Stein, 2003; The Royal Society, 1985, p. 10).
6. Benefits to Society as a Whole – Is the belief that a more informed citizenry would minimise the growing concern of the alienation of the lay public from the world of

science and technology, and that the institutionalised and elite image of science that leads to alienation of the public, widening the gap between science and the public, would be diminished.

7. Intellectual Benefits – Is the view that the promotion of science becomes part and parcel of the promotion of intellectual culture itself.
8. Aesthetic Benefits – Supports the argument that science is a distinctively creative activity of the modern mind, and that there is a desire and need to preserve the culture of science for the same reasons we want to preserve rare books, conserve beautiful buildings, and promote the arts.
9. Moral Benefits – Responds to the ethical argument for promoting science. It is governed by the belief that increasing the public's ability to be objective and critique science will lead to enhanced outcomes, particularly when dealing with ethical and moral arguments that often attract negative attention from the public, such as stem cell research, animal cruelty and issues involving humanitarian plights.

These nine arguments provide an overview of the motivations for the perceived benefits from greater communication with the public. This list is by no means comprehensive as it does not reflect the diversity of opinions amongst science communication scholars, policy makers and scientists. Over the past few decades the field of science communication has been subject to myriad attempts to define its practices and purpose. It has been argued that the principles of communication stem from a process of negotiation, one of mutual understanding between science and the public; often described as a process of generating mutually acceptable knowledge, attitudes and practices in science (Gregory & Miller, 2000).

Science literacy was a primary motivator of the PUS movement, based on the belief that increased knowledge in science would have positive flow-on effects for the public's relationship with science. During this time the 'deficit model' of communication dominated the field. The phrase, a spin on the term 'knowledge deficit', was coined by science communicators to illustrate their past mistakes. The deficit model of communication purports that the public's disinterest and scepticism towards modern science and technology can be attributed to a perceived deficit of adequate knowledge about science and scientific methodology. It was believed that by providing sufficient information to the public the 'knowledge deficit' could be overcome, thereby resulting in a change in the public's perception of the value and meaning of science and technology (Dickson, 2005; Pitrello, 2003; Quaranta, 2007). The deficit model of communication focuses on the interests of the scientists, not the public, supporting a 'textbook style' of knowledge dissemination through a repetition of facts (Pitrello, 2003) with the aim to educate the public (Stocklmayer, 2013) through one-way methods of communication.

One-way methods of communication were considered, by science communication scholars and policy makers, to be the predominant communication model used in the PUS era and for deficit model communication (Pitrello, 2003). Through this often top-down unidirectional method of communication information consistently flows from the informed scientific community to the lay public receiver (Pitrello, 2003). One of the primary limitations of this model is that it does not consider the receiver; assuming that the public is passive and exclusive in the reception of information. In reality, this view does not address the influences of context, the public's diversity and demographics, prior understanding and experiences, conflicting interpretations, attitudes and opinions, and the effects of information from competing sources (Dickson, 2005; Gregory & Miller, 2000; Sturgis & Allum, 2004).

The nature of the deficit model approach to communication and its one-way methods are appealing as they enable the prompt communication of a single direct message. Yet one-way methods have their limitations: no matter how well crafted the message is and straightforward the content may appear to be it will not always be able to answer the questions people ask (Gregory & Miller, 2000; Sturgis & Allum, 2004). One-way methods are not optimum for presenting information that is broad in scope, contains differing opinions, scientific controversies or require prior understanding. These communication aims are better suited to what are considered two-way communication methods, such as dialogue.

An influential 2000 review of the PUS era of communication highlighted that the deficit model was unsuccessful in achieving its aims (House of Lords, 2000). Since this review the deficit model has been heavily criticised in the literature, being disavowed in light of more dialogical and two-way methods of communication. Following the end of the PUS movement and the renouncement of the deficit model, the deficit model's limitations feature extensively throughout the literature. In discussing its limitations, Dickson remarks that

> Those who came up with this [deficit] argument were entirely correct in pointing out that this type of thinking, combined with the desire to overcome public scepticism, motivated much of the early 'public understanding of science' movement — and indeed continues to do so in many parts of both the developed and the developing world.
>
> They were also correct to point out that the hypothesis on which the model is based is highly flawed. Increased knowledge about modern science does not necessarily lead to greater enthusiasm for science-based technologies (2005, paras. 12-13).

Dickson goes on to add that it can in fact lead to the opposite by raising new concerns in the public (Dickson, 2005).

In addition to increased scientific literacy the desire to increase the public's trust in science was another of the early motivators of the science communication movement, based on the belief that the public's distrust in science was due to a lack of understanding. Despite the efforts of the PUS era, the public's rapidly declining trust in science was one of the main factors that led to the supposed demise of the deficit model and the end of the PUS era. However, public trust remains an important motivator of science communication, in particular in democratic decision making (Dickson, 2000; Mejlgaard & Stares, 2012; Wynne, 2006).

There is some evidence in the literature to suggest a relationship exists between knowledge and trust, yet the literature indicates that the deficit model had failed to increase the public's trust in science – in fact having the opposite effect. Wynne discusses the widespread emphasis on the perceived need to restore the public's trust in science, investigating how the traditional deficit explanations of public mistrust are continuously reinvented after being discredited and supposedly abandoned in the early 2000s. Wynne states that post 2000 the 'overt abandonment of the deficit model has been more apparent than real' (2006, p. 213). He continues:

> the huge ferment of new millennium of the 'public engagement with science' activities has been based, albeit ambiguously on closer inspection, on replacing the previous deficit model's primitive one-way assumption about educating an ignorant public into '(scientifically) proper attitudes' with an alternative two-way dialogue (2006, p. 213).

Here Wynne comments on the persistence of the deficit model and how the public engagement literature that supposedly superseded it makes the assumption that the public is keen to take part in 'scientific decision making', is capable of doing so and is resentful at being excluded (2006, p. 219).

The Public Awareness of Science and the Public Engagement of Science and Technology

In 2000 the House of Lords issued a report – 'Science and Technology – Third Report' reviewing the past 15 years of COPUS and the PUS movement. The Report highlighted that not only was the public's science literacy decreasing, but the public's interest in and support of science and scientists was also waning, resulting in public unease and distrust towards the scientific community (House of Lords, 2000; Kim, 2007; Priest, 2001; Sturgis & Allum, 2004). Furthermore, due to negative experiences with the public in the past, scientists themselves were retreating rapidly from public debate (House of Lords, 2000; Reflexives, 2006; Sturgis & Allum, 2004).

The report highlighted that the public's relationship with science was in a critical condition. It emphasised that the public's confidence in scientific advice provided to the government had been significantly damaged due to a series of events, instigated by the Bovine Spongiform Encephalopathy (BSE) outbreak in the UK in the 1990s (BBC News, 2000; Dickson, 2003a; Gregory & Miller, 2000; Kim, 2007; Office of Science and Technology and the Wellcome Trust, 2001; Watermeyer, 2012). The recommendations of the 2000 report saw COPUS and the principles of PUS disbanded in favour of more engaging and two-way methods of communication, which the authors felt would address the questions of risk, trust and mutual respect. They stated that 'we [COPUS] have reached the conclusion that the top-down approach which COPUS currently exemplifies is no longer appropriate to the wider agenda that the science communication community is now addressing' (Dickson, 2005, para. 16). These changes brought about the current era of Public Awareness of Science (PAS) and Public Engagement of Science and Technology (PEST) movements that built upon the foundations of the PUS era (Turney, 2002). The motivations and methods employed by the PAS and PEST movements are essentially the same, employing two-way methods of communication and a preference for dialogue and engagement with the public to enhance their awareness or appreciation of science. Throughout the relevant literature the term PEST dominates. However, treating these terms separately brings no benefit to the discussion going forward. Therefore the term PEST is used throughout this thesis and can be considered to encompass both terms.

In the early 2000s the effects of an eroded public confidence in science were especially apparent in the areas of environmental and biological science, and biotechnology. The primary example is the anti-GM movement. The public also became sceptical and even distrusting of science particularly in the areas of vaccinations, influenza and other contagious diseases, pharmaceutical companies, climate change and the broader environmental sciences (BBC News, 2000; Dickson, 2003a; Salleh, 2000; Widmalm, 2004). Some events have generated public unease, mistrust, and occasional outright hostility in the public towards science; the result being that some scientists have developed a deep anxiety about their ability to maintain their scientific pursuits, research funding and their reputation (House of Lords, 2000; Pitrello, 2003).

The 2000 House of Lords report discussed that the future wealth and welfare of society depends critically upon the enthusiasm of young people to pursue scientific careers. It presents the view that science and technology are intimately linked with the progress of human endeavours, including in the educational, intellectual, medical, environmental, societal, economic and cultural arenas. The authors add that science and engineering also make an important contribution to improved public services and the quality of life through technological and medical advancements (House of Lords, 2000). The report discussed that the public

> take for granted the contributions of medicine, engineering and technology to the quality of their lives...[but do not acknowledge that for] every new invention it has to go through an uncertain phase when only the courageous use it, in order to gather the experience for it to be used to the benefit of everybody (House of Lords, 2000, para. 1.7-1.8).

A non-hostile and science positive public is now commonly seen by the scientific community, governments, policy makers, industry as important to the scientific community (Sturgis & Allum, 2004). Hostility from the public and the media can seriously constrain, damage and even veto contentious research programs (Sturgis & Allum, 2004). As a result scientific industry and government fear that public hostility to a product or process may drive industrial investment in production or research overseas (Office of Science and Technology and the Wellcome Trust, 2001; Sturgis & Allum, 2004).

The recommendations of the 2000 House of Lords Report heralded a new era of science communication. Since the review, the idealised role of science communication has been transformed from the passive one-way methods of communication of the deficit model and the PUS era into providing inclusive, topical, diverse and engaging experiences to the public through the PEST era (House of Lords, 2000; Sturgis & Allum, 2004). This era is categorised by the use of models that focus on enhancing the public's relationship with science through two-way communication, focussed on the interests and needs of the public, not on the needs or views of scientists (Bauer, Allum, & Miller, 2007; Stocklmayer, 2001). This shift has introduced alternative concepts in science communication focussed on two-way methods of communication (Stocklmayer, n.d.; Wynne, 2006), including engagement and participation, dialogue, democracy, informal and free-choice learning, constructivism, and considerations of context and complementary techniques in communications. The following briefly discusses the differing elements of each of these concepts that fall under the remit of PEST communication in an attempt to provide an overview and to illustrate the diversity and commonalities of these approaches to two-way communication.

The primary and most common concept is 'engagement', followed by concepts of participation and dialogue. These concepts differ in some respects, yet share similar motivations in that they seek to generate shared conversations and experiences with the public through the use of two-way methods of communication. Less common concepts of democracy, learning and development; including informal, constructivist, complementary elements, and the importance of context in enhancing outcomes, all can be considered subsets with differing aims or methods under the primary concepts of engagement, participation and dialogue.

The democracy model specifically focuses on outcomes regarding policy, technology and democratic decision making (Hagendijk & Irwin, 2006; Rennie & Stocklmayer, 2003). The concept of learning and development as imagined by Russell (2006) can be considered as adaptive and dependent on the broader context of the surrounding environment of people, places and nature, where the learner's process of interactive engagement builds on their basis of understanding with things that are relevant, contextual and of interest to them. Irrespective of the motivations of PEST, the concept of learning is multifaceted in itself as it includes the differing elements of; informal versus free-choice learning, the notion of complementary learning that seeks to link both formal and informal learning experiences (Rennie & McClafferty, 1995), and constructivism where understanding is constructed through exploratory learning and is unique to the individual (Dahinden, 2001; Harvard Graduate School of Education, 2008; Rennie & McClafferty, 1995). Although individual motives may differ, there is general consensus in support of PEST and its concepts of engagement, participation, dialogue, informal, free-choice or complementary and constructivist learning, and the importance of context in enhancing outcomes.

Despite the currency of these concepts, the ends they are supposed to achieve under the PEST remit are unclear. All the key concepts are about process and means, not ends. So what are the desired ends? Do the ends differ from those sought via the PUS movement? Or are they the same ends, to be achieved via different means? This thesis explores such questions within the Australian context, specifically setting out to identify what a 'scientifically engaged Australia' might look like.

Structure of Thesis

In this thesis I draw on four sets of data to build up a picture of what a scientifically engaged Australia might look like. The methodological approach used is based on the principles of grounded theory originally developed by Glaser and Strauss (1967). This theory is well suited to this study as it enables the exploration of the meaning and content of various disparate sources of data. This qualitative method employs the constant comparative method, where analytic codes and categories are constructed from data and not from preconceived hypotheses. The depth and meaningfulness of this type of research is contingent on the ability to conceptualise data, glean insights, and analyse relationships between and among emerging categories (Hallberg, 2006; Howard-Payne, 2016; Jeon, 2004; Lo, 2016; Ong, 2012; Ruppel & Mey, 2015; Smith, 2015; Walsh et al., 2015; Whiteside, Mills, & McCalman, 2012). Over the last 50 years, the principles of grounded theory have been subject to much debate by scholars (Hallberg, 2006; Howard-Payne, 2016; Lo, 2016; Ong, 2012; Smith, 2015). From this debate, what has emerged are two primary forms of grounded theory that 'are theoretically, philosophically and practically different from each other': Glaser's classic grounded approach, and the Straussian constructivist approach (Howard-Payne, 2016, p. 51). Glaser's classic grounded theory operates within a post-positivist paradigm, employing a realist and constantly continuing comparative method, where the findings are deemed to be revealed from the data (Hallberg, 2006; Howard-Payne, 2016). This method is in stark contrast to the Straussian approach that rejects the positivist position (Hallberg, 2006). The Straussian method adopts a constructivist approach, where the findings are constructed and verified from the inter-subjective understandings of the phenomenon under investigation (Hallberg, 2006; Howard-Payne, 2016; Ong, 2012). This thesis employs Glaser's classic grounded theory approach as it is the most appropriate method to use due to its realist nature, methodological flexibility, and inclusivity (Hallberg, 2006; Howard-Payne, 2016; Smith, 2015).

This thesis is comprised of four distinct data sets: an examination of the academic and practitioner literature regarding the emerging concept of 'public engagement', the analysis of literature and case-studies that discuss the deficit model and one-way methods of communication, qualitative content analysis of Australian science communication policy documents, and the analysis of the interviews with key science and science communication policy leaders. The grounded theory approach to research is an ideal method to employ for real-world research, and when the methodology and process are intertwined such as it is here (Hallberg, 2006; Howard-Payne, 2016; Jeon, 2004; Lo, 2016; Ruppel & Mey, 2015; Smith, 2015). The analysis and critique of one dataset forms the basis of each chapter, and the thesis concludes with a synthetic discussion that draws together the four analyses.

In Chapter 2 the dataset comprises the bodies of formal and informal science communication literature that have explored the concept of public engagement. These bodies of literature are defined as those that have been published in science communication journals and book chapters (formal), or on websites connected to science communication institutions across the world (informal). The key question for this chapter is, how have science communication academics and practitioners defined engagement and its aims within their own scholarly and public domain writings? This chapter gives insight into the aspirational perspective on public engagement within the international science communication community. While this dataset is not Australia-specific, it establishes the broader disciplinary context within which Australian science communicators are debating ideas about public engagement with science.

In Chapter 3 the focus is the deficit model and one-way methods of communication. The chapter asks whether these have a legitimate role to play in a scientifically engaged Australia or if they are genuinely outdated, as per the assumptions of PEST 'best practice'. To build the dataset, this chapter draws upon the academic literature post 2000 that attempts to defend the deficit model or one-way methods of communication. This chapter provides insight into current perspectives on the deficit model and one-way communication within the current science communication environment. This chapter examines from a practitioner perspective the notion of mixed model communication featuring deficit model or one-way methods as part of a modern approach to science communication. It demonstrates the ongoing use and relevance of deficit and one-way communication through a small number of real life case studies of science communication practice. This chapter grounds the discussion of public engagement within the practical realities of working science communicators, bringing into view the contradictions between ideal 'best practice' and what is materially possible. In any imaginings of what a scientifically engaged Australia might look like, the practicalities of working life must be considered. The key question for this chapter is, can working science communicators successfully incorporate the ideals of the PEST movement?

In Chapter 4 the dataset is a number of key Australian government reports that have dealt with science communication and public engagement, and have either directly informed the development of the Inspiring Australia report or have been a subsequent report stemming from it. These reports collectively illustrate the current political environment with respect to science communication in Australia. As such, they are used in the chapter to understand what is meant by public engagement within Australian science communication policy. The key such report is the Inspiring Australia report, since it articulated the goal to create 'a scientifically engaged Australia'. The other reports are reviewed in light of what they contribute to this imagined picture of a future Australia, and what, pragmatically, Australian governments are likely to do to enable such a future to come into being. The key question is, how will public engagement with science manifest in a future Australia, according to Australian federal and state governments?

In Chapter 5 the dataset is extensive research interviews with six leaders in the Australian science policy and science communication arenas. These leaders were asked to articulate, in depth, their visions of what a scientifically engaged Australia would look like, including how they imagined the roles of the government, business and education sectors, as well as individual citizens and any other sectors of the Australian community. Neither the formal and informal science communication literature nor the policy documents articulate the endpoint of science engagement with much precision, so the aim in these interviews was to try to pin down some elements of that endpoint. The key question for this chapter is, where do these leaders think we are going? What exactly will Australians be doing once we have achieved a scientifically engaged Australia?

The final chapter of the thesis brings together the results and conclusions of these four chapters, to present a current portrait of what key thinkers believe a scientifically engaged Australia would look like, and where the gaps and contradictions in this vision lie.

CHAPTER 2 – DEFINING PUBLIC ENGAGEMENT

This chapter presents a literature review of the formal science communication literature from the mid 1980s onwards, restricted to looking at the definition of the term engagement, with respect to public engagement in science and technology. It also critiques informal literature in the form of over 40 current science communication websites from the UK, Denmark, France, Australia and to a lesser degree the US. The types of websites included in this investigation are: 'bottom up' sites such as blog and discussions forums, 'service sites' for not-for-profit organisations and enthusiasts, and sites run by government or education organisations.

Science communication as an academic discipline had its formal beginnings in the UK in the mid 1980s with the publication of the 1985 Royal Society report. Today the UK remains an important place in science communication both in practice and within the literature. This long history of science communication in the UK means that much of the modern literature and research remains focussed within the UK and hence so does the academic debate. For that reason much of what is discussed and talked about in this chapter is UK-based.

History

The 1985 Royal Society report identified a crisis in public trust and understanding of science (Cobern, 1993; Gregory & Miller, 2000; Hein, 1991; Riegler, 2001), this in turn led to the formalisation of science communication as a discipline. In 2000 the House of Lords issued a report – 'Science and Technology – Third Report' reviewed the PUS movement thus far, and from this point scholars coined the 'deficit' view of the public as a description of the past views (House of Lords, 2000; Irwin, 2001; Rogers-Hayden & Pidgeon, 2008), where 'implicated in the deficit diagnosis was a unidirectional transmission model of scientific knowledge between active scientific worker and passive public receiver' (Bickerstaff, Lorenzoni, Jones, & Pidgeon, 2010; Watermeyer, 2012, p. 753). It is the House of Lords report that initiated the discussion and further provoked the deficit model critics to argue 'that the public was not only able to competently converse dialogically with the scientific community but also actively contribute to issues of science governance…and even collaborate in research through a process of "interactional expertise"'(Watermeyer, 2012, p. 753). It is at this point that the role of the public was finally 'recast from "bit" to "key" player' (Watermeyer, 2012, p. 753), as argued for by early researchers such as Wynne (Watermeyer, 2012), bringing about the public engagement era of science communication of increased involvement of the public in political decision-making and research agendas Wynne (2006).

This point marked the shift within science communication principles to the citizen-centric approach of public engagement (Besley, 2012; Bickerstaff, et al., 2010; Public Agenda, 2008; Watermeyer, 2012). Scholarly scrutiny shifted from the public's deficit of knowledge to the performance of those who spend public monies (Wilkinson, Bultitude, & Dawson, 2010). The motivation behind this shift was the idea that involving the public in political decision making will remedy the public's crisis of confidence (Bauer, et al., 2007), through 'talk of public dialogue and engagement [that] has become increasingly commonplace in Europe' (Bickerstaff, et al., 2010; Irwin, 2006, p. 299). As a result, the PUS era of science communication and the need to educate the public has been replaced with the PEST movement motivated by the governments' interest in and concern about the relationship between science and the public (Watermeyer, 2012). This new movement sees a change in terminology where the 'public's engagement' has become the focus of modern science communication activities (Wilkinson, et al., 2010). However, there are those who are not as idealistic. Irwin states that the perception of a public deficit remains, by those involved in scientific governance, but this time rather than it being a cognitive deficit it is now a deficit in public trust (2006). Some authors, such as Lewenstein (2003a), argue that the terms used in the science and society movement such as PE and 'public participation' are vague and require further elaboration, yet when used in appropriate situations give true political power to non-scientists in making decisions about scientific and technological matters that affect society at large.

Bauer et al. (2007), in their reflection on the last three decades of PUS research, outline three "paradigms" within this body of research, each associated with a perceived type of public deficit. These paradigms have chronological correspondences yet do not supersede each other as each can be found in science communication practice today. Each paradigm highlights particular problems and offers preferred solutions. The first paradigm they identify is the Science Literacy movement of the 1960s, which is based on an assumption of the public's deficit of knowledge, and proposed literacy measures and increased education. The second is the Public Understanding movement from after 1985, which describes a public deficit of attitudes and education, and proposed to change attitudes through knowledge. The third is the Science and Society movement from the 1990s onwards, based on the assumption of public deficits of trust in experts, where participation and deliberation are proposed as solutions (Bauer, et al., 2007, p. 80). These three paradigms function as markers in the evolution of science communication and provide a useful narrative to frame this discussion.

Part 1: Definitions and aims of public engagement

Because the stakes are so high and the promise of PE is great, it is important to differentiate between the aims and motivations of the public engagement movement, and the definitions of PE, and the variety of mechanisms that PE can encompass. That is the aim of this chapter.

A review of the literature reveals that most authors define what they mean by 'public engagement' in their own way for the purpose of their research. This is not surprising. But the lack of uniformity in defining and discussing the terminology can be problematic as authors can be using the same terms but their meanings differ. As such, there is no clear, commonly referenced and consistent definition of PE in the science communication research or practice literature.

Research Councils UK (RCUK) defines public engagement with research as an

> umbrella term for any activity that engages the public with research, from science communication in science centres or festivals, to consultation, to public dialogue. Any good engagement activity should involve two-way aspects of listening and interaction (2013, p. 1).

In addition, RCUK extends this definition further by defining the terms: science communication as 'a one-way process to give information'; opinion research as 'a process whereby opinions are collected for consideration, but without in-depth discussion of the issues (e.g. opinion-polls)'; consultation as 'a formal process which allows reaction and response to policies/proposals'; and public dialogue as 'a form of deliberative (i.e. over time) participatory engagement where the outcomes are used to inform decision-making' (Research Councils UK, 2013, p. 6; n.d.). In other words, RCUK defines public engagement (hereafter, PE) very broadly.

Rowe and Frewer (2005) propose three different descriptors to differentiate initiatives that at some time in the past would have been considered under the banner of PE. Their descriptors are based on the flow of information between participants and sponsors and are:

> **Public Communication:** where information is conveyed from the sponsors of the initiative to the public, predominately a one-way flow of information where feedback is not required or specifically sought.
>
> **Public Consultation:** where information is conveyed from members of the public to the sponsors of the initiative, following a process initiated by the sponsor without engaging in a formal dialogue, here information flow is considered to be one-way.

> **Public Participation:** where information is exchanged between members of the public and the sponsors, where some degree of dialogue takes place and information flow is considered to be two-way (2005, pp. 255-256).

Aside from these distinctions in the direction of information flow, the academic literature tends to fall into one of two categories in terms of defining PE aims. The majority of the academic literature that discusses PE is concerned with the idea of PE as active involvement of the public in science, particularly in policy and decision making. A smaller subset of the literature seems to use PE to mean increasing the public's appreciation of the value of science and technology, or making science more interesting to people. Science communication websites that focus on promoting PE mostly fall into the latter category.

Definition 1: Engagement as active involvement

Definition one encompasses those arguments for greater PE where authors identify perceived benefits and outcomes that will be realised through greater active involvement by the public. The main focus of definition one is the relationship between the public, politics, policy and decision making. Many authors discuss at length this relationship and all but a few papers consulted for this review mention it.

There is a general consensus within the literature that increased PE in general is seen as desirable. Overwhelmingly authors advocate for PE based on the belief that greater involvement by the public is required for the greater good of society, particularly in policy and decision making (Bauer, et al., 2007; Bickerstaff, et al., 2010; Delgado, Lein Kjolberg, & Wickson, 2011; Irwin, 2006; Powell & Colin, 2009; Rogers-Hayden & Pidgeon, 2007; Rowe & Frewer, 2000, 2004; Rowe, Marsh, & Frewer, 2004; Rowe, Poortinga, & Pidgeon, 2006; Walls, Rowe, & Frewer, 2011; Wooden, 2006).

Authors Rowe and Frewer in their 2000 and 2004 reports provide the most comprehensive description of PE, defining it as 'the practice of consulting and involving members of the public in agenda-setting, decision-making, and policy-forming activities of organizations or institutions responsible for policy development' (2004, p. 512). Rowe and Frewer provide a good summation of the rise of the modern science communication era of PE, which they attribute to a decline of public confidence in the processes surrounding policy decisions and a decline of public trust in decision makers and experts. They note that for various reasons, governments are increasingly seeking public opinions on policy issues in a more direct and specific manner than ever before. While some may have noble reasons for PE, undoubtedly there is some level of pragmatism here whereby a consulted public is often more likely to be supportive (Rowe & Frewer, 2004; Rowe, et al., 2004). Rowe and Frewer's main argument outlines how in recent years the UK government has called for a greater increase in what they say is public participation at both national and local levels in domains such as health care, the environment, transport and even local government. This shift marks the move away from expert advice acting as an authoritative source to one where citizens have a voice in framing government decisions (Frewer & Salter, 2002; Rowe & Frewer, 2004).

Authors Rowe et al. (2006) discuss this rise in many democratic societies of the PE approach of involving the public in policy setting, outlining that 'engagement is seen as something of an antidote to difficulties associated with the traditional manner of setting policy' (p. 353). They argue that the more inclusive methods of PE will remedy the difficulties of traditional policy setting which include a lack of trust in policy setters and decision makers. Building on this, Rowe, Horlick-Jones, Walls, Poortinga and Pidgeon (2008) note that it is 'partly in response to a perceived loss of trust in governments and expert bodies, [that] a "novel" approach to policy-making has emerged, rooted in the idea of "public engagement"'(p. 420). These authors outline the theory that the benefits would include the attainment of more satisfactory and easier decisions, greater trust in decision makers, and enhanced public and organisational knowledge, but note that there is little empirical evidence to support this (Rowe, et al., 2008). However, scholars caution that the public does not use 'all available information when making decisions about new technologies, instead utilising ideologies, religious inclinations and familiar media coverage' in addition to other sources of information relevant to the individual (Scheufele & Lewenstein, 2005; Wilkinson, Dawson, & Bultitude, 2012, p. 45).

These definitions get at the conceptual understanding of public engagement as a strategic endeavour to improve decision making from a democratic perspective (Rowe, et al., 2008), through involvement of an informed and engaged public (Wooden, 2006). In this conception, PE becomes a solution to scientific decision making (Delgado, et al., 2011) and a remedy for initiatives which require some form of public input (Rowe & Frewer, 2004). PE is a response to a perceived need for greater policy input and decision making (Rowe, et al., 2004) going beyond one-way communication to an 'interactive and iterative processes of deliberation among citizens (and sometimes organisations), and between citizens and government officials' (S. Phillips & Orsini, 2002; Powell & Colin, 2009).

In essence, there are two schools of thought on the growing interest in PE: one considers PE to be an application of a recognition of basic human rights regarding democracy and procedural justice, and the other promotes PE from a pragmatic sense that implementing unpopular policies may result in antagonism and reduced trust in government bodies (Rowe & Frewer, 2000, p. 5).

This relationship between the motivation dichotomies of PE, of the co-construction of knowledge, increase in trust in science and decision making and an improved relationship with science, and how they relate to the definitions of PE presented here is represented in Figure 1.

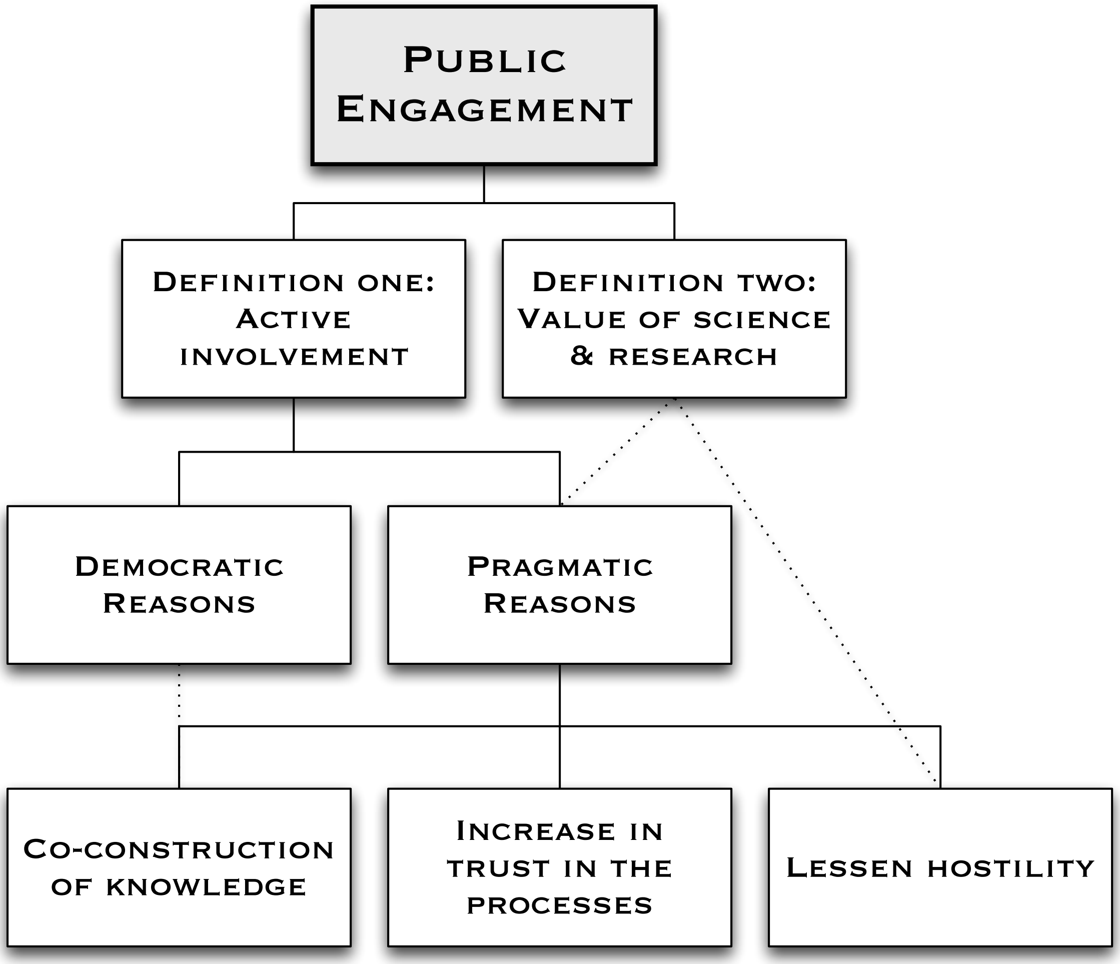

Figure 1. A representation of the relationship between the three dichotomies of motivations of PE and the definition of PE presented here. The solid and dotted lines represent direct and indirect relationships respectively.

Some authors have proposed PE as a solution to concerns that scientists often fail to provide useful guidance to those outside academia on policy debates or communication activities (Besley & Tanner, 2011; Poliakoff & Webb, 2007; Powell & Colin, 2008, p. 93). Others, such as Phillips and Orsini, describe PE with an emphasis on its impact, as 'the purpose of contributing meaningfully to specific public policy decisions in a transparent and accountable way' (p. 11). Furthermore, there are those that have the view that 'it is not possible for the practice of science to be completely unfettered from public opinion since scientific research must be accountable to contemporary concerns about values and ethics' (Wooden, 2006, p. 1058). The subtle differences present in the literature highlight different motivations and the aims behind PE activity. One school of thought is that scientists and policy makers have failed to include the public, which has the right to participate in and even direct public decision making. Others see PE as a consultative and collegial process whereby decisions are reached to the mutual benefit of all and in a transparent manner. The differences lie in the motivations, where one seeks to remedy a perceived deficiency of public consultation, because it is seen as the right thing to do; whereas the latter seeks to create a mutual and productive relationship of public consultation, more for the greater good of science communication; lending itself somewhat towards the motivations present in definition two.

Many scientists also now support PE. When Allspaw (2004) interviewed scientists about it, she found that generally they viewed the public's involvement in science policy as desirable (p. 425). Interestingly Allspaw (2004) also reports that 'both researchers and regulators agree that public involvement is desirable; however, many question if the public are interested in contributing to the debate' (p. 420). This raises a new doubt over public motivation, not just public ability.

It is thought by some that PE will bring legitimacy to decision making (Williams, 2010). Irwin (2006) notes:

> conceived largely in response to an apparent legitimation crisis, the new assumption appears to be that greater public consultation over scientific and technological developments can eliminate (or at least reduce) subsequent opposition to technical changes and achieve broad social consensus (pp. 299-300).

This new found transparency and openness is intended to rebuild public trust and draw the public into decision making, establishing a more responsive culture for innovation (Irwin, 2006). In making this observation, Irwin identifies more pragmatic motives for PE than the rather more idealistic frame identified by other commentators such as Fisher, Lee, and Cribb (2013).

Motivation - democratic decision making

Many scholars take the view that PE is key to democratic decision making. A widely cited example of the public's assessment and decision making of scientific and technological developments, where broad agreement already exists that the public should play a greater role (Einsiedel, Jelsøe, & Breck, 2001; Goven, 2003; Rogers-Hayden & Pidgeon, 2007; Wilkinson, et al., 2010). However, opinions differ with regard to the scope of public participation. Some argue that the public 'should be actively engaged in scientific assessment and evaluation where they demand to do so or where science supporting the decision process is particularly contentious or uncertain' (Chilvers, 2008, p. 434). Others take the democratic argument that, given the magnitude and range of impact that technology has on citizens' lives, citizens have the collective right to shape the conditions of their lives through greater public involvement in assessing and regulating impacts and advancement of technology (Goven, 2003). The ideal is that through greater PE, the public will be able to inform technological advancement, policy and political decision making, and in particular, PE will enable deeper consideration of the broader social values and concerns of the public that are often not factored in in technological advancement (Einsiedel, et al., 2001).

Following the earlier attempts at PE regarding genetically modified (GM) crops in the UK, nanotechnology in the US and the overwhelming negative public response to these technological developments; governments, policy makers and science communication practitioners have recently become aware of the importance of early public engagement with respect to emergent technologies, and this is reflected in the science communication literature (Callon & Rabeharisoa, 2008; Einsiedel, et al., 2001; Horlick-Jones, Rowe, & Walls, 2007; Irwin, 2001; Rogers-Hayden & Pidgeon, 2007; Rowe & Frewer, 2000). Many arguments for engaging the public with decisions about emergent technology are similar to those for more generic decision making, but the difference with emergent technology is the potential, and ease, for a negative public to quash research programs. Here pragmatic motivations also come into play.

An additional argument for PE is that lay knowledge can in fact enhance expert knowledge to address specific problems or situations, by providing context or re-framing of the problem (Horlick-Jones, et al., 2007; Wilkinson, et al., 2010). It has been cited that the public typically have a wider range of considerations than technical experts, scientists and policy makers in their reasoning about emergent technology and scientific developments, in particular considering matters that are of relevance to everyday life (Horlick-Jones, et al., 2007). Ideally PE not only enacts democratic ideals, but also contributes to the co-construction of knowledge.

In this context, upstream engagement is a characteristic of the active engagement of the public in science policy formulation and decision making. Upstream engagement has the theoretical ideal of guiding development in science and technology by familiarising the public with the content earlier in the process before commercialisation (Delgado, et al., 2011) resulting in policy that is effective, relevant and viable (Goven, 2003). It is a PE approach designed to get upstream input from the public on emerging issues, where this contextual approach can provide opportunities for non-experts in science discussions at an early stage of the research and development process and in advance of significant applications or social controversy (Besley & Tanner, 2011; Rogers-Hayden & Pidgeon, 2007). An ideal example of the use of upstream engagement is in PE over emergent technologies to encourage dialogue and deliberation between the affected parties. This is particularly useful for potentially controversial issues (Rogers-Hayden & Pidgeon, 2007).

Discussion in the area of upstream engagement, dialogue, technology development and innovation, draws on the significant body of science, technology and society (STS) and sociology of scientific knowledge (SSK) literature. This body of interdisciplinary literature considers the relationship between social, political and cultural values and scientific research, innovation and technology development, and the affect they have on one another. It is important to acknowledge that science communication as a formal discipline has emerged in part out of the STS/SSK literature. Evidence of this lineage is apparent in the following discussion on upstream engagement and dialogue as it draws heavily on the strong stream of STS/SSK literature. Scholars in this area note that early engagement does not mean that controversy will be avoided or that such avoidance should even be a goal. Scholars caution that PE should not recreate a new deficit model where objections to new technologies are seen as occurring from a lack of early public engagement (Rogers-Hayden & Pidgeon, 2007). In reality 'upstream dialogue may even lead to greater differences of opinion than seen with downstream issues' (Rogers-Hayden & Pidgeon, 2007, p. 359). A primary example of this is the failed PE initiative on GM foods in the UK (Frewer & Salter, 2002). Scholars Rogers-Hayden and Pidgeon (2007) summarise Wilsdon, Wynne and Stilgoe's comments in their 2005 report, stating that for PE to be 'truly upstream it should invoke a range of questions that challenge the agendas and practices of science itself' (Rogers-Hayden & Pidgeon, 2007, p. 355). Wynne discusses the notion of PE outlining the complexities of the process, stating how in the ideal PE possesses the elements of

> proper ends and purposes of knowledge, and the proper conditions of distribution, ownership and control of the capacity for and practice of scientific knowledge production. It would also involve a socially and ethically informed debate about the relations between scientific knowledge and other legitimate forms of knowledge and practice, for example with respect to health care, agriculture and food, indeed, all areas where scientific innovation impinges on society (2006, p. 219).

Wynne outlines how ideally PE should have the opportunity to actually inform or significantly influence the technology development process. Others expand on this view, emphasising the role of top-down processes in achieving these aims (Gauvin & Abelson, 2006). Horst (2003) states that what is required is 'to orchestrate public debate as initial top-down processes because it is expected that it will create bottom-up effects' (p. 233), or as Irwin (2006, p. 303) summarises it, a 'top-down commitment to the bottom-up'.

The complexity of upstream engagement in political decision making about science and technology is not just limited to PE but also the speed at which scientific knowledge is agreed upon. The concern is that there is a discrepancy in the speed in which scientific decision making and political decision making occurs (Collins, 2002; Stilgoe, Owen, & Macnaghten, 2013). In response to this perceived inability for science to respond to the speed of political decision making, scholars Collins and Evans (2002) propose an alternative perspective of 'responsible innovation', they remark that

> decisions of public concern have to be made according to a timetable established within the political sphere, not the scientific or technical sphere; the decisions have to be made *before* the scientific dust has settled, because the pace of politics is faster than the pace of scientific consensus formation (2002, p. 241).

Scholars seek to give legitimacy to the political technical decision making process, as 'science and innovation have become increasingly intertwined and formalised within research policy' (Stilgoe et al., 2013, p. 1568). Authors Stilgoe et al. (2013) seek to address this legitimacy of decision making as they reflect on the notion of responsible innovation, presenting a framework in an effort to 'articulate and explore four integrated dimensions of responsible innovation: anticipation, reflexivity, inclusion and responsiveness' (p. 1568). Collins and Evans (2002) also address the issue, conceptualising it as three waves of science studies. The first wave of 'positivism', ran from the 1950s into the late 1960s, described an environment where

> good scientific training was seen to put a person in a position to speak with authority and decisiveness in their own field, and often in other fields too. Because the sciences were thought of as esoteric as well as authoritative, it was inconceivable that decision-making in matters that involved science and technology could travel in any other direction than from the top down (p. 239).

Wave one was superseded by the second wave that followed from the 1970s, often referred to as 'social constructivism'. In this wave, science had become reconceptualised as a social activity with an emphasis on the 'social construction' of science. Wave three emerged not to replace wave two, but to extend it in the modern environment addressing concerns of 'expertise and experience' as it seeks 'to weight contributory expertise, interactive expertise and referred expertise, along with translation and discrimination, when judgements about a variety of public-domain technologies are made' (Collins & Evans, 2002, p. 272) in order to support and give legitimacy to political technical decision making. The 'third wave' as described by Collins and Evans seeks to 'disentangle expertise from political rights in technical decision-making' (2002, p. 235). Here the authors highlight the problem with technical decision making in the public domain, stating that

> [s]hould the political legitimacy of technical decisions in the public domain be maximized by referring them to the widest democratic processes, or should such decisions be based on the best expert advice? The

> first choice risks technological paralysis: the second invites popular opposition (Collins & Evans, 2002, pp. 235-236).

This framework seeks to explain the disconnect between scientific and political decision making, yet it is by no means a widely accepted framework (Jasanoff, 2003; Rip, 2003; Wynne, 2003). Wynne (2003) questions the oversimplification of the relationship between science, and politics, and the misunderstanding 'of "the problem of legitimacy" for science in public policy' (Wynne, 2003, p. 402). Other scholars call into question the legitimacy of this framework. They criticise it as it misunderstands the relevant literature, the role of expertise in the public domain, the purpose of public participation in democratic decision making, and that it fails to consider context (Jasanoff, 2003; Rip, 2003).

There is a focus on public policy and public decision making as one of the motivations behind public engagement. In the informal, web-based, science communication practitioner literature, service and government focussed websites are those most likely to imply that the motivation for PE is to improve dialogue between the public and policy makers. Many sites have a strong link with public policy (DIISR, 2010; Euroscience, 2012; Royal Academy of Engineering, 2012), while others have aims of better enabling

> policy making by fostering capacity within the policy-making community to commission and use excellent public dialogue. This will ensure that all future policy involving science, technology and innovation is robustly developed, informed by public concerns and aspirations and based on all the available evidence (Involve, n.d., para. 3).

Many websites convey the desire to build, through PE, a 'democracy in which problem solving triumphs…and where public policy reflects the thoughtful input and values of the nation's citizens' (Public Agenda, 2013). The exception among the informal literature consulted for this section of the thesis is science centre websites and network and event coordination websites, which do not link PE explicitly to public policy. Most of these sites rather have general aims of inspiring, exciting and motivating people, particularly young people, with science and technology Through PE, many websites share the desire to seek to build a 'democracy in which problem solving triumphs…and where public policy reflects the thoughtful input and values of the nation's citizens' (Public Agenda, 2013). The exception is science centre websites and network and event coordination websites which do not link PE explicitly to public policy. Most of these sites rather have general aims of inspiring, exciting and motivating people, particularly young people, with science and technology (Danfoss Universe, 2009; Danish Science Factory, n.d.; Ecsite, n.d.; Experimentarium, n.d.; Exploratorium, 2013; Leach, 2005; Questacon, 2013b; UK Association for Science and Discovery Centres, n.d.). Education oriented science communication websites similarly tend not to link PE to public policy motivations, with aims focussed on enhancing 'the quality and impact of learning and teaching' in science (ScienceTalenter, n.d.; The Association for Science Education, 2013; The Higher Education Academy, 2013). Bottom-up sites, individuals or locally organised groups, tend to only discuss public policy in general terms of the evolution of science communication, where public policy only forms part of the history and/or discussion of PE (Australian Science Communicators, 2013; Brown Jarreau, 2011).

A subset of the PE academic literature concerned with public policy focuses on increased public knowledge and scientific literacy. Here the emphasis is on building citizens' capacities to participate in upstream dialogues, decisions, and public policies, in particular those related to emergent technology (Chilvers, 2008; Powell & Colin, 2009; Rogers-Hayden & Pidgeon, 2008). Irwin (2006) highlights the prevalence of this view in identifying that the modern communication environment has a dominant 'inclusive' voice stressing public dialogue and a second 'scientistic' voice that states that the public can only contribute if it is properly educated and informed.

The goals of PE activities are seldom clearly articulated and the processes used range from one-way transfer of information as education and outreach to two-way intensive deliberation (Powell & Colin, 2008). Despite the apparent shift away from knowledge oriented goals, knowledge transfer remains a motivation of PE within the literature. Borchelt and Hudson (2008), providing evidence as to the persistence of the motivations of the past PUS era - of increasing science literacy and understanding in the public – in the modern PE era, where:

> research-performing institutions increasingly say they have traded in their old, top-down models of science literacy and public understanding for the new buzzwords of "public consultation" and "public engagement." But the philosophy behind consultation and engagement seems, on closer inspection, not to have changed much at all (para. 10).

Following the apparent demise of the deficit model and the PUS era it has become unpopular, even unpolitic, to seek knowledge-oriented outcomes. Thus much of the literature has an *implicit* focus on knowledge construction, as opposed to the *explicit* aims of a few. Modern definitions of PE aim 'to build citizens' capacities to participate in upstream dialogues, decisions, and public policies' and decision making related to emergent technologies (Powell & Colin, 2009, p. 328; Rogers-Hayden & Pidgeon, 2008). However, Watermeyer's (2012) recent survey of UK scientists' public engagement behaviours found that the majority of engagement activity occurs more frequently as communication (open days and public lectures) rather than as participation (active policy and decision-making activities). Further to this point Palmer and Schibeci (2012) discuss the plethora of science communication models, proposing a new typology that is focussed on the element of 'peer communication' between scientists. This theory is founded on the premise that scientists seek recognition from their colleagues, in addition to introducing an element of competition with their colleagues. Palmer and Schibeci (2012) believe that PE activities should have the primary aim of 'peer communication', with a focus on 'knowledge exchange', where recognition and competition between peers play a key role. The implicit aims are provoked by this element of peer competition and focus on the importance of the communication relationship with the public and the transfer of knowledge, with explicit aims of knowledge creation and the general preference by research bodies for communication approaches that educate the public.

The persistence of knowledge transfer as an aim of PE is discussed later in the chapter. However, the persistence within the formal and informal literature of knowledge construction in PE warrants further investigation.

Motivation – pragmatism

There are those who take a pragmatic view of PE in decision making: that early upstream engagement with the public will prevent strong rejection of proposed advancements. Some policy formulators may be 'more concerned with increasing public confidence in the policy process itself, rather than truly seeking the views of the public' (Rogers-Hayden & Pidgeon, 2007; Rowe, et al., 2004, p. 90), where others merely seek a smooth pathway to public approval and adoption (Barnett, Burningham, Walker, & Cass, 2010; Fisher, et al., 2013). Authors Borchelt and Hudson (2008) describe PE in terms of a particular 'endgame' of public confidence in decision makers and 'public empowerment', in which PE 'craft[s] sustainable policy that enjoys public confidence' through 'a real and meaningful mechanism[s] for public input to be heard far enough upstream in science and technology policymaking and program development to influence decisions' (paras. 1 & 13). Here the authors outline what they consider to be the 'real mark of successful public engagement: rather than insisting upon the public's deeper appreciation and understanding of science, its primary goal is scientists' deeper understanding of the publics' preferences and values' (para. 15). Palmer and Schibeci (2012) discuss how PE is not always an equal relationship. The public is given the opportunity to voice concerns and ask questions, but it is the scientists conducting the activity that are more concerned with promoting the merits of scientific knowledge in the interests of lessening hostility and engendering support.

Even engendering social empowerment and democracy can be considered a pragmatic action that stems from motivations to address a number of perceived sources of potential crisis in government, namely deficits of knowledge, trust and legitimacy (Chilvers, 2008; Horlick-Jones, et al., 2007; House of Lords, 2000; Lewenstein, 2003a). PE through active public involvement is believed to create 'capacities for social empowerment' within the public (Delgado, et al., 2011; Rowe & Frewer, 2000). The idea is that through social empowerment the public's perceptions will change, and 'exposure to a wider range of public knowledges, values, and meanings can create science that is more socially intelligent and robust' (Chilvers, 2008, p. 422; Leach, 2005).

The PE movement was in part brought about to remedy the loss of trust in decision makers that resulted in public scepticism and poor communication with the public regarding policy and decision making (Walls, et al., 2011). Engagement seeks to achieve wider involvement of society in the policy making process, resulting in regained legitimacy, trust in policy makers, political efficacy, enhanced democracy and/or a decline in disputation and improved policy decisions (Blair, 2002; Delgado, et al., 2011; Walls, et al., 2011). This has much in common with the PUS phase of science communication (Bauer, et al., 2007) but with the added emphasis of achieving 'social consensus through engagement' (Irwin, 2006, p. 303).

Definition 2: Promoting the value of science and research in the public arena

The second major way that PE is applied in the literature is to describe activities focussed on communication of science and its achievements, with the aim of increasing the public's recognition and appreciation of science (Rowe, et al., 2006).

The most common descriptions of PE under this definition come from the informal literature, including websites of government departments, government funded organisations, trusts, publically funded, independently funded, member supported or charity supported science communication organisations.

RCUK provides one of the most comprehensive descriptions of their goals with respect to PE through their recent public engagement strategy, outlining their vision as:

- to help society to value and have confidence in research processes and outputs;
- for public engagement to inspire young people to pursue research careers; and
- to increase the societal and business impact of research by creating a culture where:
    - the research sector and researchers themselves value public engagement as an important activity;
    - an awareness of social and ethical issues is one of the factors informing research decisions (Research Councils UK, 2013).

RCUK see PE as the creation of a culture where researchers value PE activities and have an awareness of the social and ethical issues that inform research decisions. The RCUK believes that, through PE, research directions and decisions will be more responsive to society, having a positive impact in return for investment, that society will share in the benefits of shared knowledge, and that students' experiences will be enriched, improving the supply of skilled people to the research base and the UK economy (Research Councils UK, n.d.).

Some scholars provide evidence of the persistence of the desire for PE activities to educate the public and increase scientific literacy through the communication of scientific facts (Allspaw, 2004; Barnett, et al., 2010; Irwin, 2006; Palmer & Schibeci, 2012; Seakins & Dillon, 2013; Stocklmayer, Durant, & Cerini, 2011). Seakins and Dillon (2013) specify PE mechanisms used in science centres and museums to enhance learning, while Stocklmayer, et al. (2011) advocate a hands-on science program with mothers based on the type of science their children are learning in high school, to equip parents with the skills to help their children with their homework. These motivations to educate differ from the deficit model, because the motivation is not purely to remedy a deficit in understanding in the public for their own good, but rather to increase the appreciation of science for the greater good of science, to encourage students into science based careers, to humanise the scientific pursuit through modern communication mechanisms of PE. The differences in the motivations are subtle; here there is also a small element of the value of science. Other scholars such as Goven (2003) and Watermeyer (2012) emphasise the importance of humanising science to enhance the outcomes of PE activities. Evidence of PE activities that fall under the remit of definition two are more common within the informal literature than the formal academic literature. Some authors such as Delgado, et al. (2011), as part of their argument in support of PE, also imply secondary motivations that PE is the right thing to do. Additionally, much of the informal literature, in particular science centre websites and informal websites such as blogs and other social media communication also have secondary (some even primary) motivations that PE is the right thing to do for the 'greater good'.

Science centres are a primary example of this. They have an implied consideration of the audience more than is evident within other areas of the informal literature, however the consideration of the audience is not explicit nor is it universal across the informal literature. Science centres focus on building positive experiences with science, as they strive 'to promote greater understanding and awareness of science and technology within the community…[with the commitment] to making that experience fun, interactive, and relevant' (Questacon, 2013b, para. 2) and that through this young people will 'understand, explore and enjoy developments, inspiring the youth to make a better world' (Danfoss Universe, 2009; Danish Science Factory, n.d., para. 3; Ecsite, n.d.; Experimentarium, n.d.; Exploratorium, 2013).

Education oriented sites demonstrate PE motivations. Focussed on serving ‘as a framework for inspiration, learning and knowledge’ (ScienceTalenter, n.d.), they have aims of stimulating interest in, recruitment and quality teaching in science, technology and health through education (Health, 2007), with the belief that this in turn will result in greater understanding and ‘increased interest in science, technology and health’ and recruitment into these disciplines (Danish Science Communication, 2013; Health, 2007; ScienceTalenter, n.d.; STEMNET, 2012; The Association for Science Education, 2013; The Higher Education Academy, 2013).

Arguably the most commonly promoted and farthest-reaching method of PE in practice is in media and science journalism. This strong historical link between media and science communication (Australian Science Communicators, 2013; SciDev.net, 2013) means that many websites highlight and encourage science journalism as one of many ‘different types of engagement and communication activities’, as effective methods of engaging with the public (Danish Science Factory, n.d.; European Science and Events Association, 2005; Experimentarium, n.d.; Wellcome Trust, n.d.). A number of websites include, as part of their suite of resources, dedicated resources for media and journalism (Association of British Science Writers, 2012; British Council, n.d.; Euroscience, 2012; SciDev.net, 2013; Science Media Centre, n.d.; Society, n.d.; Stempra, 2010; The British Science Association, 2012; Wellcome Trust, n.d.), not only for the benefit of science communicators but also for ‘training the scientific community to work with the media’ (UK Government, 2012). These websites provide insight into PE in action. Many of those sites entirely focussed on media and science journalism are based on a mission of providing ‘for the benefit of the public and policymakers, accurate and evidence-based information about science and engineering through the media, particularly on controversial and headline news stories when most confusion and misinformation occurs’ (Science Media Centre, n.d., para. 3). The UK-based Science Media Centre website further emphasises the strong connection between media and science in a more negative manner than other similar sites, stating its philosophy as, ‘the media will DO science better when scientists DO the media better’ (Science Media Centre, n.d., para. 2).

Service websites, including those of science centres, event coordination and formal science communication networks, predominately address the aims and motivations of definition two of PE, with their strong focus on communicating or showcasing the value of science. In addition to the motivations of science centres noted earlier, service websites and networks share the common desire to highlight the importance of informal science communication activities as ‘inspirational’ mechanisms (European Science and Events Association, 2005). These websites enable shared platforms that support an exchange of activities that lead to inspirational outcomes, some with aims ‘to increase young people's choice and chances through science, technology, engineering, and mathematics’ (Australian Science Communicators, 2013; Danish

Science Communication, 2013; Euroscience, 2012; Science Festival Alliance, 2013; STEMNET, 2012, para. 1). They illustrate what actually occurs in practice and provide commentary on PE activities from the 'coal face'.

To a lesser degree bottom-up and education focussed sites share the same motivations of communicating the 'value of science' but have additional aims of discussing science communication as a discipline (Brown Jarreau, 2011; Stempra, 2010) in action as it occurs through, the media and science journalism (Association of British Science Writers, 2012; SciDev.net, 2013; Science Media Centre, n.d.), and as shared practitioner forums focussed on education (Health, 2007; ScienceTalenter, n.d.; The Association for Science Education, 2013; The Higher Education Academy, 2013).

From the review of the formal and informal literature it is apparent that PE can encompass a broad range of aims and motivations, and may therefore garner very wide appeal as a term. However, breadth can be both a positive and a negative. On the positive side there is a plethora of aims and associated motivations to encompass all requirements. On the negative side there is a plethora of uncoordinated, untargeted and ad hoc motivations that obscure both intention and focussed content. The following section addresses the breadth of science communication mechanisms associated with each of the two PE definitions.

Public engagement mechanisms

There is general consensus of the importance of PE in the literature, yet tensions arise from opposing ideas about PE. Additional confusion can arise when the choices regarding which mechanism or model of PE used is not evident, or lacks justification (Delgado, et al., 2011).

The era of PE as the ideal model of science communication is now over 15 years old, yet still there is no significant theory that 'has emerged as to what mechanism to use in what circumstance to enable effective engagement' (Gauvin & Abelson, 2006; Metcalfe, Alford, & Shore, 2012; Mirza, Vodden, & Collins, 2012; Rowe & Frewer, 2005, p. 260). In part this is due to the confusion over the PE typology, which has numerous descriptors such as 'dialogue', 'interactive', 'two-way' or 'consultation' model, where citizens actively use their science knowledge as well as drawing on knowledge that is specific to a local context, in an often unequal relationship (Palmer & Schibeci, 2012). Added confusion arises when discussing the direction of the PE activity as it can be 'characterised as either top-down organised processes or bottom-up grassroots phenomena' (Delgado, et al., 2011, p. 832; Irwin & Michael, 2003; Rowe

& Frewer, 2005) or as ‘invited’ or ‘uninvited’ communication (Delgado, et al., 2011; Wynne, 2007).

Rowe and Frewer (2005) are the primary advocates of the PE discussion, and they propose a way forward by further categorising the different communication mechanisms in terms of their significant features, to enhance their variables such as participants and effective transfer of information. The following discussion identifies PE mechanisms and assigns them to the most appropriate definition of PE.

PE activities with an upstream element can be categorised as mechanisms that address the PE aims outlined in definition one. Goven (2003) lists myriad of mechanisms that have been developed to enable the public to participate in assessment of emerging technology including citizens’ juries, citizens’ panels, planning cells, scenario workshops, and consensus conferences, which differ from opinion surveys and public hearings by providing an opportunity for ‘informed, reflexive deliberation among participants’ (p. 424). Bauer, et al. (2007) in their commentary of upstream communication also put forward a comprehensive list of activities drawing on the UK House of Lords Report’s (2000). In addition to those mentioned by Goven (2003) Bauer et al. (2007) add ‘national debates to engage the public and rebuild trust’, where PE should be undertaken upstream at the early stages of development to enable early input rather than reactions to already established facts (Bauer, et al., 2007, p. 85; Powell & Colin, 2009; Wilkinson, et al., 2010). These are common PE mechanisms associated primarily with public participation and definition one.
In addition to the upstream emphasis, PE mechanisms that have a focus on rebuilding trust, or enabling better policy and national decision making, are common mechanisms for PE activities with aims in definition one. Public meetings or hearings are the more traditional forms of PE often focussing on health and environmental issues (Besley & Tanner, 2011). Dialogue is highlighted as a successful mechanism for PE under definition one. Taken to its most radical extent dialogue can facilitate the mutual exchange and co-construction of knowledge.

Broadly, the consensus model transposes well in multiple national and socio-cultural contexts beyond its origins in Denmark (Einsiedel, et al., 2001). The Danish consensus conference model is the premier example of a consensus conference. Here experts are solicited by members of the public to respond to their questions, as opposed to experts presenting their research to a passive and assumingly receptive audience (Powell & Colin, 2009). Einsiedel, et al. (2001) describe the consensus conference process as a group of 12 to 15 lay citizens that have chosen a controversial technological issue to examine. Identifying key issue areas, they cross-examine experts, to arrive at a consensus position to present to policy makers and the general public. An important part is that the deliberations are conducted by lay citizens

(Einsiedel, et al., 2001). The authors argue that the consensus conference is an extension to existing democratic structures, not an alternative. They state that the 'consensus conference, as a model of deliberative democracy, may be seen as one response to the challenge of making technological decisions more legitimate' (Einsiedel, et al., 2001, p. 95).

Delgado, et al. (2011) discuss how the move to upstream PE has led to some creative invited forms of engagement from cultural festivals, card games, debates in schools, presentations in cafes, citizen schools, and ad hoc or informal consensus conferences without a focus on decision making or a fixed specific objective. These more creative forms of PE can be considered to be focussed on inspiring the public, communicating a particular message and thus would be considered PE mechanism that address the aims of definition two.

Café Scientifique programs are popular forms of public engagement for definition two; these programs take place in a collegial social setting such as a café or a pub. Here participants interact with one another and a scientist as the presenter (Mayhew & Hall, 2012; Wilkinson, et al., 2010). A common café scientifique format includes a short presentation, followed by a hands-on activity (Mayhew & Hall, 2012), questions and answers or a group discussion (Canadian Insitute of Health Research, 2008; Salisbury Café Scientifique, n.d.). Interactivity, through two-way communication, is one of the most important elements of a café. Effective presenters 'must be able to paint a picture in the mind of each audience member with the concept they wish to convey' (Mayhew & Hall, 2012, p. 5).

Interactive science centres and science shows associated with them are prime examples of science communication activities, which sit within definition two, existing purely for the sake of sharing the value of science or to excite the public towards science, rather than informing policy debate (Danfoss Universe, 2009; Danish Science Factory, n.d.; Ecsite, n.d.; Experimentarium, n.d.; Exploratorium, 2013; Questacon, 2013c; Science Festival Alliance, 2013; UK Association for Science and Discovery Centres, n.d.).

The effectiveness of PE mechanisms varies depending on the aims they seek to achieve. The relative effectiveness of PE mechanisms is consequential to this discussion and is investigated further later in the chapter.

From this review it is evident throughout that PE activities are often named, but rarely described and lack detail. One broad description of PE is of a 'mutually beneficial, and routine dialogic interface between experts and a heterogeneous public' (Watermeyer, 2012, p. 755). Generally there is a lack of evidence in the literature analysing and discussing the differences in PE activities. This aside, most authors do manage to highlight a variety of PE activities (Horlick-

Jones, et al., 2007), however, critical discussion over their appropriateness in achieving particular PE outcomes is lacking. This may be due to the confusion in the typology of PE.

Not only is the terminology uncertain, the mechanisms for undertaking the activity and measures of effectiveness are loosely defined. Rowe and Frewer argue that

> the lack of clear definitions hinder research activities into the effectiveness of the different mechanisms, but also the sheer abundance of mechanisms – often highly similar to one another, differing only in the order in which a number of process are implemented – creates research problems in the sense of multiplying potential objects of research (2005, p. 253).

What is apparent from this review is that the literature, both the formal academic and the informal websites, lacks a precise definition for PE, and therefore a clear understanding of its mechanisms. Confusion over the aims and objectives of PE feeds into the mechanisms and vice versa resulting in an all-encompassing method of science communication encompassing many motivations, objectives and mechanisms; rather than an exclusive and targeted communication method with clear objectives and appropriate mechanisms. Without clear objectives success cannot be measured or achieved.

Dillon (2011) emphasises confusion around PE, stating that

> [p]ublic engagement is another term whose meaning has shifted significantly in quite a short space of time. Originally the term referred to scientists and policy makers engaging with the public about the direction and focus of science research. Now, however, the term seems to be applied to any contact between scientists and the public including outreach and entertainment (p. 6).

Wilkinson, et al. (2010) go further, stating ‘engagement has not developed at the speed anticipated, innovative elements are often shrouded in traditional forms, and the definition of the term engagement remains an area of both academic and practical debate today’ (p. 392).

The following section continues the review of the formal literature, presenting discussion on the common difficulties and limitations associated with PE activities.

Part 2: Public engagement difficulties

PE is not without its difficulties. Measures of the impact of engagement activities is limited and generally restricted to qualitative reports often on democratic participation in decision making and policy processes; in line with ‘the [misleading] normative assumption that public engagement is inherently a good thing' (Watermeyer, 2012, p. 756). Quantitative evidence of the impact of PE activities is either lacking or non-existent.

PE activities are potentially susceptible to ulterior motives, influence or manipulation by stakeholders (Cooke & Kothari, 2001; Frewer & Salter, 2002; Powell & Colin, 2009; Watermeyer, 2012; Wynne, 2006), because outcomes are often regulated by elites through the superficial involvement of citizenry in setting policy agendas (Cornwall & Gaventa, 2000; Watermeyer, 2012). Goven (2003) argues that bias among PE organisers is inevitable and that strategies need to be in place to counteract this.

As discussed above, some scholars argue that PE only occurs to quell anticipated public resistance (Irwin, 2006; Powell & Colin, 2009) or that it often only occurs after a controversial social or ethical question has arisen in relation to new technologies (Rogers-Hayden & Pidgeon, 2007). In these circumstances PE may only serve as a 'public relations' act whether it is intentional or not (Rogers-Hayden & Pidgeon, 2007). Furthermore, Rogers-Hayden and Pigeon (2007) caution that prior to entering into a PE exercise the public can hold firmly established positions of themselves that can in turn influence the success of the PE exercise.

Additionally, some scholars argue that more public involvement is not necessarily desirable or advisable in every instance. For example, the direct involvement of all members of the public in science and technology developments is not always feasible, and it can also cause tensions to arise in deciding who is a 'relevant' participant (Delgado, et al., 2011; Jasanoff, 2003; Rowe, et al., 2004). Furthermore, Jasanoff (2003) in her critique of H.M Collins and Robert Evans' discussion paper argues that there is a boundary between science and politics that should be upheld and that PE activities need to acknowledge that there is 'legitimate expertise on technical issues; not everyone can or should hope to participate in all aspects of technical deliberations' (p. 390). Chilvers (2008) discusses how the public fits into the scientific appraisal process, arguing that the existing PE models do not sufficiently consider constructivist perspectives on knowledge, analysis and deliberation and how they influence the public. In addition to the constructivist perspectives scholars Scheufele and Lewenstein (2005) and Wilkinson, et al. (2010) discuss how the public do not use all available information, instead they are inconsistent and selective in the information they seek to use. Allspaw highlights in her 2004 study that 'scientists have made it clear that they will not accept methods that are not based in proven opinion-gathering methodologies' and that one way to appease them would be a compulsory participation system, similar to jury duty (p. 427). Others such as Rowe and Frewer (2000) discuss the debate behind the motivations for public participation noting that policies involving the public must balance the desire to foster legitimacy and support for decisions with concerns about being driven by 'the crisis of the day'. All these scholars note that apart from ignorance, there are other factors that limit the public's potential to contribute to policy discussions, including attitudes, beliefs and motivations. The authors also present the counter arguments here; that often there are also limitations in the knowledge of experts who often disagree with one another, and that the public is not necessarily irrational in its concerns over risks and should be able to participate in risk management (Rowe & Frewer, 2000).

Other difficulties with PE identified by scholars include concerns over how many PE activities required intensive 'in-person' time with citizens, with ongoing communication and support (Powell & Colin, 2008), and the prevalence of top-down PE activities where scholars argue that this is somewhat unavoidable due to the inequality of power between scientific institutions and society (Powell & Colin, 2008). In a later study by Powell and Colin they investigated whether meaningful citizen engagement can be achieved through top-down institutionally initiated activities (2009). They found that fostering bottom-up public engagement from the top-down is an extremely time consuming endeavour and that it is unlikely that academics will engage with the public in this way. The authors outline how most engagement exercises are relatively short-term which does not allow the public to become knowledgeable and confident in organising (Powell & Colin, 2009) or participating in these activities (Gauvin & Abelson, 2006; Mirza, et al., 2012). In addition, the authors report that their efforts to nurture and create an independent citizens' group over the previous three years were not successful and caution that public groups that endorse certain viewpoints, particularly about technology, are no longer a 'lay representative' public group but rather a 'special interest' or 'stakeholder' group (Powell & Colin, 2009).

Not all PE initiatives are problematic. Chilvers' (2008) study into participatory appraisal of effective practice highlighted that a small number of respondents expressed that 'scientific analysis should be transparent to participants within the process and make underlying uncertainties and assumptions explicit' (p. 436). Most of the respondents felt that any 'information provided should be appropriate, meaningful, and understandable from the perspective of those participating' and responsive to the needs of the participants. Participants should have access to specialist expertise and have control over who is providing assistance and that the deliberative process between the participants and the scientists is highly interactive and symmetrical (Chilvers, 2008, pp. 438-439).

While public consensus may appear to be a noteworthy endeavour, the question remains whether consensus is either achievable or desirable within the complex and ever changing conditions of contemporary life (Irwin, 2006; Irwin & Michael, 2003). Irwin (2006) investigates the politics of public talk with the following observations: that the terms 'consultation', 'dialogue', and 'engagement' are open to interpretation and reformulation; and that the 'representativeness of the public' is of concern. Irwin notes that while the 'pursuit of public consensus appears to be a noteworthy characteristic' (p. 315), as evidenced in his study on the GM Nation debate, the link between 'engagement' and 'enhanced trust' is tenuous and it is naïve to expect that public trust and confidence can be re-built through talk. Furthermore, Irwin warns that control over the framework for engagement, regardless of the method used, constitutes an important source of power. By comparison, Bauer, et al. (2007) argue that as 'academically grounded as it may be, [PE] often ends in political advice with a pragmatist outlook' (p. 85); as policy makers are now the 'focus of closed executive training seminars and advisory panel discussion rather than of publically documented research results' (Bauer, et al., 2007, p. 85).

PE has a key role in the relationship between the public, politics and policy decision making. Some scholars identify that this is often a problematic relationship in which the roles of facilitator as designer and moderator are highly complex, ambiguous and often cannot be clearly defined from one event to another (Chilvers, 2013). In addition to these criticisms, others discuss how the objectives of some PE activities are loosely framed without direct policy roles yet they are aimed at affecting external decision-making rather than internal cultures (Bickerstaff, et al., 2010). Rowe and Frewer (2000) report on the increasing contention that PE in policy making is necessary to acknowledge democratic ideals, enhance trust and transparency. They note that the relative usefulness of PE activities is difficult to ascertain; emphasised by the absence of any optimal benchmarks and general confusion over what is meant by 'effectiveness'. The authors state that it is difficult to declare which one method is best, but suggest that the most appropriate methods for PE are likely to be hybrids of traditional methods in which mechanisms complement one another (Rowe & Frewer, 2000; Wilkinson, et al., 2010).

Conflation of terminology

Terminology inconsistencies within the literature, both formal and informal, lead to confusion over the definitions of dialogue, public participation and public engagement. Authors themselves tend to use the terms interchangeably. The lack of consistency in using the terminology makes evaluation of activities difficult when the desired outcomes are not clear in the first place.

Rowe and Frewer discuss the imprecise definition of the key terms within what they call the 'public participation' domain (2005). After decades of what they call the 'public participation era' of science communication, the key concepts in this domain remain ambiguous in their definitions. The authors discuss these 'definitional issues', such as what is actually meant by 'participation', what would the correct mechanism for this activity be, and what reliable measures of effectiveness would be (Rowe & Frewer, 2005; Watermeyer, 2012). Rowe and Frewer seek to clarify what public engagement entails and to clarify how the various mechanisms differ from one another, stating that 'one distinction that has been made in the past is between *participation* and *communication'* and that it is inappropriate to ignore the conceptual differences between them (Rowe & Frewer, 2000; 2005, p. 254). In the literature, synonyms of uncertain equivalence such as public involvement are often used. Delgado, et al. (2011) highlight that in their study they use both the terms public participation and PE simultaneously, stating that this 'reflects the way in which these terms are largely used indistinctively in academic texts and policy documents' (p. 827). They state that there is a tendency within 'science and technology studies' to favour the term 'public engagement', though the reasons for this preference are not clearly articulated. Delgado, et al. (2011) suggest that it implies something closer to generating interest than 'participation' or that it is related to the emerging concept of 'upstream engagement'.

Palmer and Schibeci's (2012) study into research funding bodies' conceptions of science communication found that there is some 'blurring of the lines with regard to what type of engagement is suggested or encouraged, what is practised and what is formally specified in funding criteria and policy documents' (p. 5). Palmer and Schibeci not only look at Australian research funding bodies but also New Zealand, UK, and the US, stating that Western nations tend to straddle several communication types. Other nations, including China and Latin American countries, are slowly shifting towards PE but the focus remains on scientific literacy and traditional deficit style strategies (Dickson, 2003b; Jia & Liu, 2014; Polino & Castelfranchie, 2012). Scholars illustrate the confusion present in the terminology, stating that this confusion is 'inimical to conducting research and unhelpful to practitioners' (Rowe & Frewer, 2005, p. 258). The validation of the nomenclature is difficult to ascertain, where 'the uncertain equivalence of the terms, is even greater than the misnaming of the mechanisms and leads to further confusion and term proliferation' (Rowe & Frewer, 2005, p. 259).

Delgado, et al. (2011) in discussing the notion of 'upstream' in PE motivations and practices draw on Wynne's 2006 article stating that 'tensions arise from the fact that the concept of upstream PP/PE [public participation/public engagement] is based on a linear, unidirectional and oversimplified image of science-society relations' (Delgado, et al., 2011, p. 834; Wynne, 2006). This linear metaphor implies that the choices made are irreversible (Delgado, et al., 2011). Scholars state that this lack of clear definitions of public engagement may relate to the lack of agreement on how the public is included in practice (Delgado, et al., 2011).

Many scholars conflate the terms public participation, PE and dialogue in various combinations. The interchange of public participation and PE is the most common, however other combinations include using 'participatory appraisal' as a description of the engagement process (Chilvers, 2008), public consultation as a mechanism of PE (Allspaw, 2004), the simultaneous use of the terms 'upstream engagement' and 'upstream dialogue' (Rogers-Hayden & Pidgeon, 2007), the preferred use of public participation as a description of engagement (Einsiedel, et al., 2001), the preference for the term 'public dialogue' as a description of PE (Chilvers, 2013), where dialogue is a subset of engagement (Bickerstaff, et al., 2010), public debate and PE are interchanged (Horlick-Jones, et al., 2007), the simultaneous use of public participation and PE and dialogue (Powell & Colin, 2008), the simultaneous use of public participation and PE, but a dominance of the term public participation in Rowe and Frewer's work (Rowe & Frewer, 2000, 2004, 2005; Rowe, et al., 2004).

If enhanced mutual understanding is a goal, this plethora of terms used to describe modern science communication is confusing and unhelpfully problematic. However, the general consensus by scholars within the literature has PE as the prevalent term, even if its meaning remains imprecise (Goven, 2003; Powell & Colin, 2009).

Authors who do not define public engagement

Further to the earlier discussion over defining PE it is evident that many scholars do not define what is meant by the term PE in their studies. Palmer and Schibeci (2012) provide evidence of this as they investigate the conceptions of science communication in relation to 'public engagement with science' (PES) evident within science research funding bodies. The authors do not define what is meant by 'engagement' other than to say that it stemmed from the critique and end of the previous PUS paradigm of dissemination moving to a 'paradigm of dialogue and participation' or PES (p. 1). In their discussion they separate the terms PES and science communication in which the latter is the broad term encompassing PES, as often these terms are conflated as discussed earlier in the chapter. The authors go on to discuss how funding organisations seek to encourage PE, along with other methods of communication from dissemination to consultation, yet what is required and the level of communication remains undefined. The study uncovered that the UK was more encouraging of PE activities, yet the deficit model – defined in the study as the assumption that a public that 'is considered to have a low level of understanding which needs to be overcome in order to make what scientists consider to be "rational" decisions [through the use of]…a unidirectional flow of information from scientists to the receivers' (p. 2) – continues to dominate in practice. It is evident from the literature that many institutions and funding bodies have made science communication and/or

PE part of their policy, yet it is still not a central requirement to funding and is often performed as a good will exercise (DIISR, 2010; Horst, 2014; National Research Foundation South Africa, 2014; Neresini & Bucchi, 2011; UCL Public Engagement Unit, 2012).

Other scholars do not define the term PE in their studies, or use PE as a 'motherhood statement' or blanket term for communication (Allspaw, 2004; Besley & Tanner, 2011; Chilvers, 2008; Christensen, 2011; Einsiedel, et al., 2001; Fisher, et al., 2013; Heath & von Lehn, 2008; Horlick-Jones, et al., 2007; Irwin, Elgaard Jensen, & Jones, 2013; Jasanoff, 2003; Neresini & Bucchi, 2011; Rennie, 2011; Rogers-Hayden & Pidgeon, 2007; Seakins & Dillon, 2013; Stocklmayer & Bryant, 2012; Stocklmayer, et al., 2011; Wilkinson, et al., 2012).

Evaluation of public engagement is problematic

The evaluation of PE is problematic for numerous reasons, including definitional vagueness, and thus is infrequent. Many scholars agree that the practice of evaluating PE activities often lacks purpose and rigor (Braun & Schultz, 2010; Goven, 2003; Powell & Colin, 2009; Wilkinson, et al., 2010), and without evaluation of PE activities effective future PE will not occur (Neresini & Bucchi, 2011). A common issue identified by scholars is due to the typology, aims and objectives: being poorly defined it makes it difficult to evaluate because there is nothing specific to evaluate against (Bauer, et al., 2007; Irwin, et al., 2013; Rowe & Frewer, 2004; Wilkinson, et al., 2010). The question of 'effective engagement' is the focus of discussion for many scholars, who unsuccessfully seek to define and categorise this term and measure the impact of PE activities (Chilvers, 2008; Powell & Colin, 2008; Rowe & Frewer, 2004; Rowe, et al., 2004; Walls, et al., 2011). Rowe, et al. (2008) state that 'there may be no one appropriate "universal" definition of what constitutes an "effective" exercise' which only adds to the difficulties in evaluating these activities (p. 420). At present research into public engagement reveals little about which methods and mechanisms are best (Rowe, et al., 2006).

Bauer, et al. (2007) put forward an alternative explanation of this: that it may be due to the multi-disciplinary nature of science communication and the lack of common foundations. Delgado, et al. (2011) argue that the existence of different rationales creates tension in the approaches to PE, having a flow-on effect for evaluation (Horlick-Jones, et al., 2007). This and the general lack of control over the "engagement" process can severely limit the collection of necessary data (Rowe, et al., 2008).

What scholars do agree on is that the evaluation of PE activities rarely occurs, and when it does the quality of evidence is typically poor and therefore uninformative (Rowe, et al., 2008; Walls, et al., 2011; Wilkinson, et al., 2010). The 'lack of clear guidelines on good practice [in PE] is arguably a consequence of an absence of evaluations on the effectiveness of past engagement exercises' (Walls, et al., 2011, p. 241) and a lack of structured studies on its effectiveness stems largely from uncertainty on how to conduct evaluations (Rowe & Frewer, 2004).

Rowe, et al. (2004) report on Rosener's 1981 study which lists four problems inherent in conducting evaluations: that PE is complex and value laden; there is no consensus or widely held criteria for judging its success and failure; no agreed upon evaluation methods; and few reliable measurement tools available. The authors go on to note that informal evaluations are weak as they do not produce hard data needed for analysis. They criticise some informal measures such as the number of participants attracted. The authors discuss how evaluation is complex and multidimensional, noting that some authors have begun stating criteria for judging success, by producing definitions of effectiveness. Here the success of a PE mechanism may depend on the particular criteria used to measure its effectiveness (Rowe & Frewer, 2004). Furthermore, difficulties can arise in the evaluation of PE due to the variety of ways any one method can be implemented, which can then prove to be effective or ineffective depending on how it was conducted (Rowe & Frewer, 2000).

Rowe and Frewer (2000) propose a standard framework based on a number of reoccurring themes and requirements for success present in the academic literature. This framework presents nine criteria under the two main themes of 'acceptance criteria, which are related to the effective construction and implementation of a procedure, and process criteria, which are related to the potential public acceptance of a procedure' (p. 11). This framework forms the basis of further work in this area by Rowe, et al. (2004), Rowe and Frewer (2004), and Rowe, et al. (2008). Rowe and Frewer's original work in 2000 provides the most comprehensive overview of the criteria:

Acceptance criteria:

- Representativeness; public participants should comprise of a broadly representative sample of the population of the affected public.
- Independence; the participation exercise should be conducted in an independent, unbiased manner.
- Early Involvement; the public should be involved as early as possible in the activity as soon as value judgements become salient.
- Influence; the output should have a genuine impact on policy.
- Transparency; the practice of approach and decision making should be transparent.

Process criteria:

- Resource accessibility; public participants should have access to the appropriate resources to enable them to successfully participate.
- Task definition; the nature and scope of the task should be clearly defined.
- Structured decision making; the use or provision of appropriate mechanism for structuring and displaying the decision making process.
- Cost-effectiveness; the procedure should take into account considerations of cost-effectiveness (pp. 12-17).

Furthermore, Chilvers (2008) discusses the literature presenting at least seven effectiveness criteria identified in the literature for which considerable consensus exists. These criteria are closely related to Rowe and Frewer's 2000 framework.

Powell and Colin in their 2008 study identify how 'few academics and governments attempting to "engage in engagement" are clear about their goals and desired outcomes, and whether or not the processes they facilitate are likely to meet these ends' (p. 126). Rowe, et al. (2008) argue for the inclusion of the public in the design and evaluation of PE activities. This however assumes that the public is interested and eager to become critically engaged, and then there are those that believe evaluation of PE activities overlooks the publics' attitudes (Felt & Fochler, 2008; Wilkinson, et al., 2012). Harvey (2009) investigated the deficiencies of present evaluation of engagement activities commenting that that current evaluation frameworks tend not to consider what actually happens in terms of participant participation, and prevailing evaluation practices cast participants as instrumental yet exclude their experiences, which could be dramatic or emotional.

Rowe, et al. (2008) discuss how little empirical evidence exists to support the theory that greater PE leads to its putative outcomes of greater trust in science, enhanced policy and decision making, support for science and technology and the myriad of other societal, economic and environmental benefits. They suggest that if the 'act of engaging with the public indicates success…[then] *evaluation* itself becomes a superfluous concept' (p. 420) as they simply state that 'evaluation is difficult' (Rowe, et al., 2008, p. 420).

Lack of public representation in public engagement activities

A common problem with PE activities is that the samples are often not particularly 'representative' of the public (Rowe, Rawsthorne, Scarpello, & Dainty, 2010; Wilkinson, et al., 2012).

Scholars discuss that invited forms of PE predetermine who is considered a 'relevant' participant but also how they should participate. This influence impacts on potential opportunities for possible alternative responses (Delgado, et al., 2011; Irwin, 2001, 2006; Irwin & Michael, 2003). Participant selection is difficult as motivations for desired outcomes can affect selection. The use of a 'neutral public' group may be more useful than interest groups or stakeholders, where consulting 'lay citizens' is arguably the most powerful choice to achieve social legitimacy (Delgado, et al., 2011). In addition, some scholars state that it is important for PE activities to be presented as demographically inclusive, where participants comprise a broadly representative sample of the affected population involved in the discussion (Bickerstaff, et al., 2010). The existence of a truly 'neutral' public is debated as often the public's behaviour is considered marginal (Irwin, et al., 2013), yet polarized interest groups, such as alarmist or pro-scientific, can sometimes dominate discussions (Allspaw, 2004).

The question of who 'the public' actually is is not agreed upon (Allspaw, 2004). Scholars state that bias can arise from the self-selection of participants, as generally participants in PE activities are self-selecting, attracting 'likely candidates' (Besley, 2010; Bickerstaff, et al., 2010; Rogers-Hayden & Pidgeon, 2007; Rowe, et al., 2006). Therefore it is unclear how much engagement activities are ever fully inclusive or genuinely representative of the full gamut of public concerns (Besley, 2010; Powell & Colin, 2008; Rowe, et al., 2004; Rowe, et al., 2010).

Outcomes of evaluation

The evaluation of PE activities is not perfect; those responsible for the evaluation of an activity can pick and choose respondents' input which they feel are relevant and useful. One solution to minimise bias is to include an independent observer in the process (Walls, et al., 2011). The outcomes of evaluation can depend on the evaluation mechanisms used (e.g. web-based versus postal), as PE activities can have clear demographic differences in the respondents. One study showed respondents who used web-based surveys were more likely to be male, younger, and from affluent areas, were predominately well educated and had already made up their minds on the issue (Rowe, et al., 2006).

Favourability is an important outcome in the PE process associated with definition one as discussed earlier in the chapter. It is defined as representing support for a decision itself, while 'acceptance' represents satisfaction and belief in the legitimacy of the decision-making process. Besley (2010) found that 'believing one receives a fair outcome is associated with decision favourability, while all forms of fairness perceptions are associated with acceptance' (p. 256). Similarly fairness in relation to procedures and outcomes is often used to evaluate risk communication using public engagement (Renn, Webler & Wiedemann, 1995 as quoted in Rowe & Frewer, 2005).

Powell and Colin (2009) discuss that the aim of some engagement exercises is to influence policy making, yet evidence suggests that they have had little discernable impact in this regard. Likewise, Williams (2010) notes that there is little evidence to suggest how bottom-up PE could be practical or effective. Indeed, the 'danger is that participatory approaches serve to minimize/ignore uncertainties, limit social and natural diversity, and lose sight of antagonisms, differences, and exclusions' (Chilvers, 2008, p. 445; Hinchliffe, 2001). In addition, Goven (2003) reports that consensus conferences are likely to be held under imperfect conditions where these participatory methods may reinforce the already dominant expertise and existing restrictive framing of the debate, rather than opening up the policy issue to new knowledge and values facilitating the integration of societal needs. Rowe, et al. (2010) add that there exists

> uncertainty about the extent of actual influence of the public in research prioritisation, there is also the important question of whether the public really ought to be involved. That is, do the public have the capacity to appreciate the intricacies of science proposals? What criteria are the public likely to use to select proposals for funding? And how do these match the criteria employed by scientists and reviewers? (p. 228).

Moreover Irwin, et al. (2013) state that there is a sense that 'while "critical disappointment" is very common in the area of public engagement' that this should not lead to polarised for and against positions to be formed. Instead all activities should be viewed as contributing towards the overarching goal to achieve enhanced democratic engagement with science and technology (p. 122).

Rowe, et al. (2010) report on a 2004 study by O'Donnell and Entwistle, who conducted a survey on consumer involvement in health-related research, and found organisations provided a variety of reasons for involving consumers in their decision making processes. Importantly they found that respondents 'reported knowledge about the actual effects of involvement was relatively low, suggesting that engagement idealism has yet to be grounded in reality' (p. 227). This issue of public involvement in decision making also has resonance beyond the UK (Rowe, et al., 2010).

The persistence of knowledge transfer as an aim of public engagement

Since 2000 there has been a concerted attempt among science communicators to explain, define and improve the new vision for engagement; however throughout the literature there is evidence by some scholars of the persistence of knowledge transfer and learning as an aim of PE. Not all scholars share the same opinions, yet there remains evidence to its ongoing occurrence and occasionally underlying support for the transmission of knowledge under the guise of PE. Within this there are two facets - the intent to educate the public versus the intent to inform through the dissemination of information. The former is deficit model communication, based on the assumption that the public is deficient and in need of education for their own good, where the latter can be described as one-way communication. The difference is the intent motivating the communication activity. Scholars Barnett, et al. (2010) in their study into how defintions of the public are imagined by renewable energy industry practitioners identified these two facets of PE: one of information provision, and the other the common view that the public lacks knowledge and this is a concern. When discussing the persistence of PE in the literature, since not all scholars agree, it is important to make the distinction between those who exhibit deficit model motivations based on the attitude that the public is deficient and in need of education, and those who seek to transmit knowledge through one-way mechanisms.

Some scholars highlight the fact that a deficit model view of the public remains one of the most common arguments for the persistence of knowledge transfer in modern science communication, motivated by a need to educate the public, as evidenced in the study by Allspaw (2004). Allspaw (2004) makes note of the statement made by a scientist that 'the best way to educate the public would be to focus on concepts and not just facts…basic education in the process of scientific research is crucial to creating an informed public' (p. 423). The study's findings highlight that scientists were encouraging towards better public education in science generally, yet were still wary about the ability of the average citizen to ever fully be an informed contributor to discussions about complicated technologies. Bickerstaff, et al. (2010), who note the persistence of 'fundamentally hierarchical models of engagement - characterized by a consumer model of the citizen' (p. 490), also report the persistent view that for many scientists the main reason for engaging with the public is the desire to educate them rather than to participate in a debate, listen and learn from them (Bickerstaff, et al., 2010). Powell and Colin share a similar view as they discuss the need for the public to have particular knowledge or skills to enable them to participate effectively. Powell and Colin (2009) argue that 'citizens need knowledge, skills, efficacy, and collective organizing skills to meaningfully engage in and affect science and technology policies over the long term' (p. 328) providing evidence of the persistence of education aims. Further to this point, Chilvers' (2008) study found that the majority of interview respondents felt that publics should have an active role or at least the opportunity to have an active role in the assessment of the development of science. This 'reasoning was underpinned by the argument that public judgements can be just as valid as those of scientific-experts, provided publics are engaged in properly informed and structured learning processes' if they have the cognitive ability to do so (p. 433). Others, such as Goven (2003) state that there are those who still believe that the public's lack of accurate scientific knowledge means that they are more emotive, possibly producing a public discussion that is both unbalanced and uninformed.

Scholars such as Irwin (2006) state that despite the new phase of science communication and PE, at the heart it 'the old cognitive deficit model is very much alive and well' (p. 302). Irwin (2006) does not suggest 'that the movement from deficit to democracy flows in one direction' (p. 304). He argues that at 'the heart of the 'new' reside some very 'old' assumptions of public deficiency' (p. 304). Irwin is not alone in his views. Other scholars discuss the persistence of deficit model views of the public, as modern PE initiatives commonly reproduce the assumptions and consequences of the deficit model and one-way communication methods, excluding lay views and preventing true 'engagement' with the public – whatever this may mean (Allspaw, 2004; Delgado, et al., 2011; Einsiedel, et al., 2001; Metcalfe, et al., 2012; Palmer & Schibeci, 2012; Watermeyer, 2012; Wynne, 2006, 2007).

Not all authors make explicit statements relating to education. The literature also highlights mixed views by scholars on the role of knowledge transfer in PE and its relationship with societal attitudes. Mayhew and Hall (2012) argue that effective engagement requires consideration of prior knowledge and social context to make a meaningful and personal connection with the audience. Others use this as a mechanism to influence attitudes or public opinion, since knowledge transfer remains persistent if the motivation is to achieve a change in the public's opinions, and further PE is seen to be needed until the public has the 'right' attitude (Bauer, et al., 2007).

Conversely, there are some scholars who simply note the use of PE as a mechanism for education or learning, without explicitly discussing knowledge transfer and one-way communication models (Braun & Schultz, 2010; Seakins & Dillon, 2013; Wilkinson, et al., 2012).

Other scholars discuss the persistence of knowledge transfer under the remit of PE without the deficit model's intent of educating the public. Borchelt and Hudson (2008) in their report provide a narrative on the evolution of science communication models, stating that it appears that

> research-performing institutions increasingly say they have traded in their old, top-down models of science literacy and public understanding for the new buzzwords of "public consultation" and "public engagement". But the philosophy behind consultation and engagement seems, on closer inspection, not to have changed much at all. [In practice], much communication currently passed off as public consultation and engagement is still one-way, expert-to-layperson information delivery, albeit in different settings like cafes scientifique, public meetings, and town halls (para. 10).

Further to this point, Watermayer's 2012 survey found that 73 per cent of respondents (medical science practitioners and researchers) answered 'transmission of knowledge' in response to the question what 'best describes what public engagement means to you' (p. 758). In addition, the persistence of common one-way communication models, such as public lectures and open days, is evident throughout the literature (Besley, 2012; Metcalfe, et al., 2012; Rowe, et al., 2010; Walls, et al., 2011; Watermeyer, 2012).

As scholars introduce PE it often coincides with a brief history of science communication and the disgracing of the PUS era and the deficit model of communication (Bauer, et al., 2007; Rogers-Hayden & Pidgeon, 2007). Some scholars have argued that 'it will remain difficult for public communication and involvement to escape the dead end of the deficit model, so that predominant among scientists is still a view of PE "as negative and one-way process"' (Neresini & Bucchi, 2011, p. 77).

Special edition of Public Understanding of Science

A special edition issue of the Public Understanding of Science journal was released in early in 2014, late in the stage of this thesis, which looks back on two decades of science communication and has 'steadily described and mapped the gradual and incomplete shift from 'understanding' to 'engagement', and the flowering of policies, initiatives and practical experiments that has accompanied this' (Stilgoe, Lock, & Wilsdon, 2014, p. 4).
A disconnect between theory and practice is apparent in this special edition through the persistence of the deficit model. Authors still 'follow earlier criticisms of the way in which dialogue continues to reflect deficit-like assumptions' (Irwin, 2014; Riesch & Potter, 2014; Stilgoe, et al., 2014, p. 5; Wynne, 2014) with authors asserting goals of science education and literacy (Haywood & Besley, 2014; Riesch & Potter, 2014) and even note the benefits of deficit model communication in terms of increasing science literacy in China (Jia & Liu, 2014).

Irwin presents a reflection and evaluation of the balance between the limitations and achievements of PE over the last 20 years, stating that 'we can safely conclude that, despite all the 'from deficit to democracy' talk, no such easy shift has been made' (Irwin, 2014, p. 73).

This sentiment is shared by Wynne, who states that over the last 20 years despite the criticism and overt abandonment of the deficit model explanations of the public they are 'continually reinvented in new forms, despite their stated abandonment' (Wynne, 2014, p. 62). Irwin, who claims his views on the prevailing deficit model have softened, now asserts that ''deficits' are fundamental to many forms of communication and as such can never be discarded' (2014, p. 73).

The upshot of this edition of PUS is that science communication in the modern era is highly political. Stilgoe, et al. (2014) assert that 'the first thing to acknowledge more openly is that public engagement has typically become a procedural response to a more fundamental political challenge' (p. 11). Attention now must be paid to the political economy and 'de facto governance' of science (Guston, 2014) and that PE is a 'necessary but insufficient part of opening up science and its governance' (Stilgoe, et al., 2014, p. 5). Irwin (2014) provides an insightful overview into the present state of practice, stating:

> there can certainly be something all too familiar about engagement initiatives which start out high on political rhetoric only to succumb to narrow issue framings, over-hasty deadlines and a recurrent tendency for officials to approach engagement exercises as if they were schoolteachers setting an end-of-term test for which most pupils are disappointingly underprepared (pp. 71-72).

Many authors comment on this complex relationship between the public and politics and the role of PE in this; whether it is about the legitimacy of PE in reaching policy recommendations (Burgess, 2014; Horst, 2014; Stilgoe, et al., 2014), the challenges associated with the notion of a 'political economy' and the ineffectiveness of PE influencing policy (Guston, 2014), or that the versatility of science is suppressed by political-economic forces, and the relationship between the parties should be based on mutual respect rather than the abject servility of the present (Wynne, 2014). Scholars also raise concerns over representativeness of the public (Sturgis, 2014), that science communicators may have over-promised on what PE can deliver, and that PE is overwhelmingly focussed on universities and other public sector bodies despite the fact that most innovation happens in the private sector (Stilgoe, et al., 2014). What is apparent in this special edition is that politics has become the key driver of science communication and that PE remains the mechanism to assist in the relationship between the public and politics and policy.

This special edition featured the usual common criticisms of PE, suggestions for new mechanisms of PE and commentary on its future direction. Jones provides the following context through his commentary:

> there will always be resistance to the idea of public engagement, if it does genuinely succeed in opening up the process of setting priorities. For some, who believe that science and politics can be cleanly separated, and that experts can provide value-free advice based purely on scientific evidence, any influence on decision making by the non-expert is quite inappropriate (2014, p. 29).

Twenty years on there still exists a lack of clarity over the role of PE in practice because the 'more public engagement is practiced, the clearer becomes the tangle of institutional motivations behind it' (Stilgoe, et al., 2014, p. 6). Complexities arise over concerns of diversity, meaningful dialogue in PE, the replication of existing power relationships between scientists and the public (Stilgoe, et al., 2014), the willingness for the public to participate in PE (Sturgis, 2014), and with those that maintain a strong view of scientific governance (Irwin, 2014; Wynne, 2014).

Other criticisms raised in the issue primarily relate to funding issues due to the Global Financial Crisis and associated funding cuts to science and science communication and their detrimental effect on PE. The impacted science and education funding environment had flow-on effects in that there has been a general decline in science and science communication. Another criticism raised was due to the rise of the internet and in particular social media in relation to their effect on the availability of knowledge (Horst, 2014; Jones, 2014; Nowotny, 2014). Furthermore, from the discussion presented in this publication it is apparent that some hold citizen science in high regard, yet it is hotly debated by others. It is featured as being an effective way of getting the public involved in science, yet many perceive that there are implications for scientists and research assistants on the availability of 'free labour' (Riesch & Potter, 2014).

In looking towards the future there is general support for the retention of PE. Despite what is occurring in practice, there is a strong underlying trend in the literature of the 'importance of 'two-way dialogue' between science actors and the public' (Sturgis, 2014, p. 38). There is a particular focus in the literature on democratic dialogue about science and technology is beneficial in its own right, along with the remaining strong view that PE is necessary for democratic control in informing political decision making and in scientific governance (Guston, 2014; Horst, 2014; Jasanoff, 2014; Jones, 2014; Nowotny, 2014; Stilgoe, et al., 2014). The new mechanisms proposed by the authors in this special edition are variations on the same theme of PE and are largely focussed on redefining the communication parameters and the relevant stakeholders, in particular a better understanding of the public (Gehrke, 2014; Haywood & Besley, 2014; Nowotny, 2014).

The question raised here, related to comments by Wynne (2014), is, are we verging on new horizons for science communication and PE or are we deceptively thinking that these new models are not simply reinventions?

Chapter summary

This chapter presents a review of the academic and informal literature relating to the term 'public engagement'. Within this literature I have identified two main definitions of PE. The first is based on the idea of PE as active involvement of the public in science with a particular focus on policy and decision making. The second definition focuses on PE as a means of increasing the public's appreciation of the value of science and technology. As discussed there is an evident difference between the formal academic literature and the informal literature from websites, in which the former predominantly subscribes to definition one and the latter to definition two.

Knowledge construction is a key element of both definitions. Consequently, it is important to note the persistence of knowledge construction as an aim of the PUS era and the deficit model into the engagement era of science communication.

The literature highlights the opposing ideas about how PE is to be defined but also the confusion over what are appropriate PE mechanisms. From this review it is evident that there are categories of mechanisms which are more suited to each of the two definitions of PE. Dialogue mechanisms which have motivations of rebuilding trust, upstream or emergent technology communication such as public meetings, citizen juries, opinion polls and hearings, consensus conference and debates are best suited to PE within definition one. Festivals, shows, games, school debates, interactive science centres, café scientifiques, and informal consensus conferences, are focussed on positive experiences and appreciation of science falling under definition two of PE.

This chapter also discusses the limitations and difficulties associated with PE, primarily confusion arising from conflation in terminology, which in turn leads into difficulties in effective evaluation of PE. The limited evaluation of PE activities that has occurred shows that PE has not achieved its original aims and influenced policy or political decision making, and highlights the additional problems and many instances of evaluation bias. Another problem with PE is the persistence of knowledge transfer as an aim of PE and one-way communication remaining as a communication method; this emphasises the disconnect between theory and practice with respect to science communication models. The following chapter will investigate this further through a review of the academic literature with respect to the use of the traditional deficit model of communication and its one-way methods of communication.

CHAPTER THREE – LITERATURE REVIEW ON THE DEFICIT MODEL OF COMMUNICATION AND ONE-WAY METHODS OF COMMUNICATION AND SELECTED CASE STUDIES

This chapter investigates the conversations present in the academic literature providing context and history as to the development of the 'engagement' era of communication. Here the discussions focus on how the deficit model of the public and the related and commonly used method of one-way communication have fared following the end of the PUS era. Much of the academic literature implies that the shift from deficit to dialogue was comprehensive and immediate; however, the following discussion considers that the shift to PEST has not been universal nor is it irreversible.

The modern era of science communication and the call for 'science engagement' has occurred in response to the criticisms of PUS era. To approach an understanding of 'engagement' from a different angle it is useful to tease apart and consider what it is encapsulated and excluded by the term.

This chapter identifies what is meant by 'the deficit model' and 'one-way', highlighting the elements that may be touted as inconsistent with the idea of 'engagement'. At the conclusion of this chapter, four case studies are presented to illustrate the reality of science communication in practice and the practical use of the deficit model and one-way methods.

The reality of science communication

Case studies into the practice of science communication provide important insight into the reality of undertaking communication activities. What is apparent from these studies is the disconnect that exists between what is proposed as 'best practice' and what occurs in reality. The cause of this disconnect can be attributed to a multitude of factors including but not limited to: a lack of understanding on behalf of the communicator as to what 'best practice' means, limited resources, specific communication agendas, stakeholder responsibilities or simply the desire of those who are doing the communication – often the scientists themselves. While achieving and operating within 'best practice' is the ideal, in reality 'best practice' is little more than a theoretical construct.

Davies in her 2008 study into the science communication practices in the UK investigated the nature and the reality of science communication in practice through a series of focus groups with scientists. She found that the majority of science communication activities are funded and/or undertaken by governments and charities, without input from science communicators. These events are not large-scale events, 'they are instead ad hoc and informal activities, such as open days or outreach programs to schools' (p. 414). Davies found that in practice it is individuals or small groups of experts, as representatives of scientific establishments, who most frequently come into contact with the public; not science as an institution in a coordinated manner. Therefore, it is the practices of individuals that shape the general view of science communication practices and behaviours.

Metcalfe, et al. (2012) investigated this notion of the 'practices of individuals' through an audit of Australian science communication activities. This report on the 'National audit of Australian science engagement activities', the first of its kind in Australia, provides insight into the practices of Australian science communication. The audit undertaken between January 2011 and June 2013, funded by the Federal Government's Inspiring Australia (IA) program, aimed at gaining

> a national picture of science engagement activities so that people involved in science communication could access the data to research trends [sic], discover new ideas, look for complementary projects and avoid duplication of activities (p. 1).

This audit arose in response to the 2011 report from the 'Expert Working Group: Developing an Evidence Base for Science Engagement Activities' stemming from recommendation 15 of the IA strategy. The survey sought responses to reported science communication activities in terms of the four main goals of IA, as discussed in Chapter 4.

The audit was conducted over the period May to September 2012, and consisted of an online survey gathering information on 411 activities from 254 respondents, plus seven focus groups run across the nation with a total of 129 participants. The respondents were predominately from tertiary education institutions, largely universities and research institutions, 'followed by cultural organisations, including science centres, museums, zoos, art galleries and wildlife centres' (p. 8).

This audit driven and framed by the IA strategy did not share the same definition of the term 'engagement' as its parent reports, as discussed in Chapter 4. The audit defines PE as part of the report's discussion rather than part of the background to the study. In framing the audit, the authors defined the term 'engagement', taken from Kang (2012), as a '"motivated affective state of individual members of publics" (Kang, 2012) when interacting with scientists or at events about science' (p. 50). This definition presents a different way to look at the meaning of the term 'engagement' than the IA strategy. In Kang's definition the concept of 'engagement' focuses on change within – the internal change of the individual – in contrast to the common definition that focuses on an external change in the form of specific actions, as used in the IA strategy. The fact the authors chose to use a different definition of 'engagement' whilst undertaking a study stemming from the IA report suggests that the authors were not in agreement with IA's definition of 'engagement'. Yet, there is little direct evidence in the report of the audit adhering to the Kang definition of 'engagement'. The actions taken by Metcalfe et al. in this audit contradict the Kang (2012) definition of 'engagement', as the audit measured 'engagement' activities through an audit of the practices of individuals, in line with the IA strategy's definition – not changes in the internal affective state of the individual as defined by Kang (2012). Despite this contradiction in the audit, which no doubt stemmed from practical considerations, Kang's definition of engagement is a useful description as it presents an alternate view of the practice of 'engagement' focussed on the change resulting from a communication activity, not a mere description of communication practices. One issue with this definition is that measuring 'engagement' would be an involved process as it would be focussed on the individual. In spite of this, and for the purposes of further exploring the aims of creating a 'scientifically engaged Australia' (SEA), I consider it a useful interpretation of the common definition of 'engagement'. Those working on promoting a SEA in the future might consider how this could be applied.

The results of the audit found that science communication activities in Australia did not adhere to 'best practice' in terms of shifting from one-way to two-way, from education and dissemination to engagement at least as it is commonly defined. The report identified that one-way methods of communication remain in practice and dominate science communication activities in Australia. The most common methods were 'lectures or educational experiences where people learn by watching, listening or viewing via public lectures, websites, newsletters and printed materials' (p. 51) - methods deemed by the authors as 'passive and one-way' (p. 51). Not only are the common communication mechanisms used one-way, the authors identified that the motivations behind most activities are not directed at individual or institutional or behavioural change, critical thinking, or public input and decision making with respect to driving science, all of which are commonly considered desirable outcomes of the PEST era of science communication.

The authors go on to state that

> many activities are moving towards more interactive engagements with the public, particularly with the dominance of face to face interactions and their high use of social media. Most of the activities captured in the audit are not about the simple dissemination of information, although there is still a focus on increasing awareness, education and scientific literacy (p. 51).

This commentary highlights the confusion on the part of the respondents surrounding the practice of science communication, the communication models used, and the motivation behind and desired outcomes of science communication in practice. Here the authors make note of the persistence of PUS-style motivations such as ‘awareness, education and scientific literacy’. The authors’ comments here in relation to the apparent shift towards PE with an increase in ‘face-to-face’ and ‘social media’ highlight the nuances and complexities inherent in understanding these communication models: neither mechanism is exempt from one-way methods of communication, so is not necessarily a move towards dialogue or similar. As noted in its parent Expert Working Group (EWG) report, the emergence of social media as a new mechanism for science communication is of note and may benefit from further exploration.

This audit identified a number of trends present in the current Australian science communication environment that are of particular note in framing the IA strategy and its goals of creating a ‘scientifically engaged Australia’. They are:

- The most common type of communication method across the sectors and the nation is one-way.
- Scientists and professional science communicators are the main people engaged in science communication. This finding contrasts with the earlier UK study by Davies (2008); in that professional science communicators appear to now be driving science communication in practice as opposed to government or charities reported in the 2008 study. This discrepancy could be attributed to the fact that the Metcalfe et al. audit was specifically targeting science communication practitioners and their activities and Davies’ study was from the perspective of scientists.
- Science communicators rely heavily on reputable scientists or organisations to ensure the science communicated is current and credible.
- Communication activities have a strong focus in biological and environmental sciences and are less likely to focus on information and computing, mathematics or engineering.
- Communication is directed at nation- or state-wide groups predominately made up of school-aged children or the general public, usually with more than 500 people targeted.
- Businesses are least likely to communicate, but of businesses, mining companies are most likely to communicate.
- The Federal Government is the major funder of science communication activities.

The audit found that the evaluation of these communication activities was primarily informal and in-house predominately using forms and surveys. The number of attendees was the most common measure of success; few activities used qualitative data or formal measurement against pre-determined success indicators. Respondents reported that past experiences were used to inform new activities, yet more often than not recent activities were merely repeats of past practices not new initiatives. Prior experience was the main determinant of whether a communication activity would be successful.

The results of this study provide a useful dataset on Australian science communication practices that can be used to inform future work, analysis and discussion. In addition to the presentation of the results, the authors propose a series of general recommendations for 'improving the quality of science engagement' at a national strategic level. In terms of future directions for science communication, the authors state that Australia would benefit from a more tailored approach to science engagement and that science communication should be a requirement of all funding grants, a view shared by its parent EWG report and the IA strategy, as discussed in Chapter 4. In investigating the different types of communication models discussed in the report, confusion arises due to the conflation of terms 'deficit model' and 'one-way', as the authors often use them synonymously. For example, Metcalfe et al. state 'for us, and for many of the focus group participants, public engagement goes beyond the mere one-way dissemination of information ('deficit' model) to a more participatory approach where people are affected and motivated by their participation in science' (p. 50).

Building on the 2012 Metcalfe et al. audit and Metcalfe's subsequent 2013 article in *The Conversation* (Metcalfe, 2013), scholars Cormick, Nielssen, Ashworth, La Salle, and Saab (2014) undertook a study into what science communicators say in relation to science communication through a 'series of workshops into impediments and solutions to best practice in science communication in Australia' (p. 1). These workshops involved 'over 250 science communicators from government to private sector agencies' (p. 2), who developed a list of ten agreed-upon principles and their actions. However, the authors themselves state that this list is conservative in nature as often the more innovative ideas put forward were not the most popular ideas, and that some of the outcomes are too broad to be truly useful. Out of the ten actions, five state that 'best practice' needs to be developed, and three are focussed on additional research grants for specific activities. These actions are reminiscent of those identified as part of the IA report. The breadth and ambiguity of the outcomes flags a potential need for a more concerted discussion of what it is science communicators are trying to achieve, and whether there are any universally shared aims or if aims are too diverse to be unified. The authors themselves acknowledge the limitations of this study stating that there is a 'need for clearer definition and examples' (p. 7) and it would benefit from a more targeted discussion with science communicators. They go on to reflect on the discord between knowledge and behaviours, proposing that first it may be necessary to ask '[just] how relevant is "best practice" in day-to-day science communication' (p. 8). This study provides insight into the current reasoning of science communicators in Australia and highlights the ambiguities around not only what it is that they are trying to achieve, but also how this should be done.

The upshot of the Metcalfe, et al. (2012) audit is that one-way methods of communication remain dominant in science communication activities across the sectors and the nation. The authors attribute this to the apparent

> time lag, and that we are still responding to a broader system that hasn't moved away beyond the deficit model, or does not know how to cast the role of the expert scientist/science communicator in this new mode of third-order thinking (p. 53).

The premise of third-order thinking is based on Irwin's (2008) article that explores different ways of thinking about science communication and risk management. In order to move away from historical and sequential descriptions of communication models, Irwin uses the descriptions 'first-order' (or deficit), 'second-order' (which has a greater emphasis on public engagement and dialogue) and 'third-order' (emphasises the relationship between the key parties). The primary feature of Irwin's 'order descriptions' is that they signify more than changes in language and communication methods, they are about emphasising the science-public relations in a wider context of science communication, moving towards 'more critical reflection – and reflection-informed practice – about the relationship between technical change, institutional priorities and wider conceptions of social welfare and justice' (p. 207). Irwin goes on to state that

> third-order thinking invites us to consider what is at stake within societal decisions over science and technology and to build on the notion that different forms of expertise and understanding represent an important resource for change rather than an impediment or burden (p. 207).

And that it

> is not simply a matter of categorising individual activities and initiatives into one order or another. As we have suggested, what might appear as dialogue to one party can look remarkably like deficit to another…[it] is about interrogating the operating assumptions and modes of thought on which individual initiatives depend and considering the practical and conceptual implication of this (p. 207).

This description of communication does not focus on preferred communication models. Instead Irwin reflects the potential that new 'possibilities emerge for forms of communication that do not simply trade in the reflexive language of deficit and dialogue, but that open up fresh interconnections between public, scientific, institutional, political and ethical visions of change' (p. 210). Irwin identifies the persistence of first-order communication and that a 'more complex (and confusing) situation now operates in which first- and second- order approaches operate in uneasy coexistence and unconsidered juxtaposition' (p. 204).

A similar view is apparent in the Metcalfe, et al. (2012) study, that identifies how, for the last 30 years of formal science communication, one-way methods of science communication continue to dominate and that perhaps one-way is a legitimate and useful communication model if embraced and used appropriately.

This chapter will investigate this further by asking:

a. How is the deficit model defined and how does it relate to one-way methods of communication?
b. Is there a legitimate place for one-way communication in a 'scientifically engaged Australia'?
c. Is there a legitimate role for deficit model thinking about the non-scientist public?
d. How do key case studies demonstrate the persistence of these communication models in real-world examples of science communication?

Defining 'the deficit model' and 'one way methods'

Much of the literature is vague on the specifics of who first coined the term 'deficit model', using generic statements such as 'coined by social scientists studying the public communication of science in the 1980s' (Dickson, 2005, para. 10). Yet there is some, albeit conflicting, evidence regarding who is responsible for originally coining the phrase. Allegedly Wynne in his 1982 book *Rationality and ritual: The Windscale inquiry and nuclear decisions in Britain* was first to conceive the term (Cotton, 2014; C. M. Phillips & Beddoes, 2013). In contrast to this claim a 2010 report by The Royal Society states that the term was 'apparently coined by John Ziman [in 1985], who was actually a member of the Royal Society group and signed off on the final version of the report' (para. 28). Regardless of its heritage the term deficit model reflected the practices of the early formal science communication movement over the PUS era, as discussed in Chapter 1.

The PUS era, and with it the deficit model, was dominant for over 15 years until the 2000 House of Lords report – *Science and Technology – Third Report* which reviewed current practices and proposed a new agenda for science communication (House of Lords, 2000). This report reviewed the attitudes and actions of both the scientific community and the lay public. It found not only that society's relationship with science was in a dire situation, due to eroded public confidence in the scientific community, but also that science literacy was not any higher (House of Lords, 2000; Pitrello, 2003).

The House of Lords Report proposed a new era of contextualised science communication calling for an increase in 'dialogue, discussion and debate' between scientists and the public (S. Miller, 2001, p. 117). It was at this time that the 'demise of the deficit model' was pronounced by UK Science Minister Lord Sainsbury to make way for more inclusive methods of science communication, aimed at addressing the questions of risk, trust and mutual respect of the PAS and PEST era (S. Miller, 2001; Turney, 2002).

Three years after the 2000 House of Lords Report and the beginning of the PEST era, Lewenstein (2003b) reviewed the current science communication environment and considered the history, scope and aims of the deficit model, and the alternative models of what he called 'contextual', 'lay expertise', and 'public participation'. Lewenstein's goal was not to judge one communication model over another but to 'understand how different perspectives on public communication of science and technology can lead to different activities and achievements' (2003b, p. 2). He states that while all this activity has taken place the question of 'whether all that vigourous activity is being "successful" is less clear, in part because there is no consensus about the goal, about what constitutes improved public understanding of science' (2003b, p. 1).

The discussions throughout the literature often conflate the terminology when discussing the deficit model and one-way communication. This section outlines the process taken in reviewing the relevant literature and seeks to clarify the terminology to enable the exploration of how one-way methods of communication and the deficit model of communication are conceptualised within the literature, in turn.

The literature this review draws upon is restricted to articles post 2000 within the science communication and education fields. A search was undertaken using a number of key word combinations of: deficit; one-way; linear; uni-directional; transmission; dissemination and didactic. Of those articles found, the field was extended through searching the reference lists of these articles.

The majority of the literature focussed on the deficit model and its supposed demise. These articles that provided a historical narration and outright criticisms of the deficit model were excluded from this critique, since their criticisms were addressed in Chapter 1 as part of the disciplinary context of this thesis. Only articles that discussed the benefits and the persistence of the deficit model of the public and one-way methods of communication are discussed here. Fewer than 20 articles were found that directly discussed the deficit model and one-way methods in more detail than just a historical narration. The majority of articles are based on the science communication and political environment in the UK. The early prominence of the UK focus in the formal science communication literature is apparent, but over time these discussions have shifted to continental Europe, Australia, the US, and to a lesser degree developing nations (Schiele, Claessens, & Shi, 2012). To date the UK remains the prominent focus of the science communication literature where similar literature in the US is more focussed specifically on scientific literacy.

Throughout this review it became apparent that often terminology is conflated when discussing the deficit model and one-way communication, with authors for example using 'deficit' synonymously with 'didactic' or 'linear' in place of 'one-way'. Broadly, these terms are essentially similar and for the most part when discussing science communication in general these can be used interchangeably, however, these terms all have subtly different meanings. Clarity and consistency over the terminology becomes paramount when discussing the specifics of communication models. For this purpose it is important to note that not all deficit model communication is one-way, with the information flow from the 'informed' to the 'deficient', and conversely not all one-way communication is based upon the deficit view of the public. Examples of conflation are evident throughout the literature, as terms are used interchangeably or without prior definition, leading to confusion over what is actually meant by the 'deficit model'. Is it the traditional deficit model based on the attitudinal assumptions of the deficient public? Or is it a description of the type of communication method – of one-way, linear, didactic or dissemination from the informed source to the public? To avoid confusion it is important to clearly articulate these conceptual differences when defining and discussing these models. For example Clarke (2003) reports on a study of communication activities between scientists and farmers. She states, 'the traditional deficit model of one-way information flow from the laboratory to the field is being replaced by a contextual model involving two-way dialogue' (Clarke, 2003, p. 198) implying that the deficit model is a model for one-way communication. Yet in the opening paragraph of the article, Clarke states that 'science communicators acknowledge the need for a move away from the traditional 'deficit' model of communication, where the science simply needed explaining for the non-specialist audience to understand, accept, and applaud' (Clarke, 2003, p. 198). These two statements by Clarke highlight the presence of subtle differences in the terminology. It is not clear in the article if Clarke is discussing the deficit model in terms of the desire to educate the public, or one-way dissemination of information, or both.

Kolb (2010) provides another example in his study that discusses comedy as a method of science communication. Kolb initially introduces the deficit model as functioning 'on the basis that the general public is incapable of understanding the complexities of science and requires intermediary figures (often in the form of the media) to translate this knowledge for them' (2010, para. 1). He then introduces engagement models of communication by stating that 'this change in approach from deficit to dialogue has meant a movement in public events communicating science from the didactic approach of lectures to more interactive offerings' (2010, para. 3). These subtle differences and inconsistencies in the language have a significant impact on the overall argument it supports. Like Clarke (2003), the phrases that Kolb (2010) and countless others have used efface any differences we might want to acknowledge between the deficit model and one way. There are numerous examples of this kind of ambiguity or interchangeability of terms present in the discussion of the deficit model and one-way communication models by many esteemed authors including but not limited to: Bauer and Gaskell (1999); Courvoisier, Clemence, and Green (2013); Jensen (2010); Lewenstein and Brossard (2006); Mellor (2008); Metcalfe, et al. (2012); Torres-Albero, Fernández-Esquinas, Rey-Rocha, and José Martín-Sempere (2011); Wilsdon, Wynne, and Stilgoe (2005); Wynne (2006, 2008).

Clarity over terminology is essential to this discussion. As such it is important to define clearly concepts such as deficit, didactic, dissemination, linear and one-way communication models. Broadly these models are often considered under the umbrella of one-way methods of communication; however, they differ in their perspective, methods and objectives. For the purposes of clarity in this thesis, I define the differing attributes of these models as follows:

- The 'deficit model' of the public is based on the *attitudinal assumption* that the public is deficient and in need of education for their own good, and that an educated public would lead to positive outcomes for science. It is the case that the communication methods that accompany deficit model thinking are often one-way, but one-way models are not an inherent part of the deficit model. The term deficit model can be seen as less of a description of the method of communication and more of a description of the motivations behind the communication process (Dickson, 2005; Kim, 2007; Wright & Nerlich, 2006).
- 'Linear' communication models are one-way communication activities that can be said to be a linear and literal transmission of information from the source to the receiver. This model was originally conceived as the 1949 Shannon-Weaver model of five elements: an information source, a transmitter, a channel of transmission, a receiver, and a destination (Communication Studies, 2011; Reynolds, 1997).
- Communication through 'dissemination' refers to a broad one-way communication model. Dissemination is where a message is broadcast from the source of information to the public domain without direct feedback from the audience. Dissemination is the

model used in mass media communications (Bjerglund Andersen, 2011; Byrne, 2011; Libutti & Valente, 2006).

- 'Didactic' communication refers to a one-way communication model from an informed source to the lay receiver that is intended to instruct, educate or improve the receiver through the transmission of information, for example an academic lecture. Didactic communication is usually accompanied by 'deficit'-style motivations, the difference being that didactic communication is associated with a formal or structured education environment (Cojocaru & Popa, 2011; Sabau & Nicolescu, 2011).
- 'One-way communication' can be considered the broad term describing the flow of information from a source to a receiver. One-way communication models can be one-to-one or one-to-many communications, where the element of feedback is not included in the description of the model (Byrne, 2011; Nisbet, 2011).

As discussed, each of the approaches to communication differs slightly in their respective perspectives, methods and objectives. In practice, due to their commonalities, multiple models can be employed for one communication activity. For example, mass media communication regarding a crisis can be considered both broad communication with a deficit model objective to educate the receiver, a mix of dissemination and didactic methods of one-way communication.

The deficit model can be defined as a top-down communication approach where the desired outcome is to increase the public's knowledge or understanding of a particular topic, driven by the attitudinal assumption that the public is deficient and in need of education, and that the attitudinal shift will be in the direction desired by the sender. This definition relates to the attitudes and motivations behind the communication rather than the mechanism or method of communication, and it is this definition that is used throughout this thesis when referring to the deficit model. The attitude and assumption is that the public's knowledge or understanding on a particular subject is deficient and that it can and should be remedied by receiving additional information from an informed source. Some of the original advocates of the PUS movement went so far as to say that the public needed to be educated for their own good, in topics pre-determined by government or scientific bodies (Holton, 1992; S. Miller, 2001; The Royal Society, 1985).

The history of the supposed demise of the deficit model is discussed widely throughout the science communication literature. Yet the literature includes works by scholars who discuss of the persistence and the reinvention of the deficit model and/or one-way communication models with varying levels of support; scholars whose work includes evidence that they themselves hold a deficit model attitude towards the public; and scholars who argue that it is the default model of communication. Therefore the next two sections address two key research questions for this chapter: is there a legitimate place for, respectively, one-way communication or the deficit model in a scientifically engaged Australia?

Is there a legitimate place for one-way communication in a 'scientifically engaged Australia'?

One-way methods of communication continue to monopolise science communication (Metcalfe, et al., 2012), not only as a popular communication choice, but also as the default communication choice by scientists (Davies, 2008; Jensen, 2010; Lewenstein & Brossard, 2006; Trench, 2008; Wright & Nerlich, 2006). Scholars such as Trench attribute this to the nature of the scientific enterprise, which inadvertently encourages one-way communication over two-way methods of engagement and dialogue (Trench, 2008). In support of this argument, a study by Davies (2008) observed the fact that models of one-way communication appear to be more readily available to those seeking to communicate in addition to being more frequently used by inexperienced communicators. The use of what are considered newer communications models, involving dialogue and participation, are more prevalent in groups with greater experience of science communication and working with the public.

There appears to be no universal consensus in the literature on which science communication models are preferred by the public, or for those doing the communicating, typically scientists. The literature is split; partly focussed on how people learn within the education domain with respect to knowledge acquisition (Brown, 2004), and partly focussed on the outcomes of specific communication activities such as museum exhibits or in terms of evaluating discrete communication activities (Serrell, 1996). The literature does suggest that the model preference depends on both the type of communication activity and the communicator's desired outcome: e.g. to educate or enthuse, where motivations of education commonly use one-way methods, as opposed to activities that seek to enthuse the public which are often two-way activities seeking public participation and dialogue. The focus of the literature, of what the researchers seek to evaluate, is primarily on the audience or on the communication objectives, not on the communication practitioner per se. In practice, scientists undertake the majority of science communication activities, and unsurprisingly they use the method that best suits them: typically a one-way communication method (Davies, 2008; Jensen, 2010; Lewenstein & Brossard, 2006; Trench, 2008; Wright & Nerlich, 2006). This highlights the disconnect between the theory and practice of science communication.

Some scholars raise concern over the need to consider what communication models will work for scientists in addition to what the public needs. Wilsdon, et al. (2005) highlight a quote by

Professor Colin Blakemore, the Chief Executive of the Medical Research Council in the UK, who stated that he was 'very committed to engaging the public…however, in the rush to openness and transparency, we need to think carefully about what models will work best for scientists, and what works best for the public' (p. 41). Professor Blakemore's statement acknowledges that science communication models are a complex problem, in which the needs of both the public and the scientists need to be taken into consideration. He outlines a noble ambition, one where communication models need to consider the benefits and practical utility for all parties (Wilsdon, et al., 2005). This presents a multifaceted problem. The literature argues that there are methods of communication that best suit the sender, such as one-way communication, and those that best suit the receiver, such as many two-way models of communication. In reality, what (if any) communication models are ideal for both the sender and the receiver?

A fundamental consideration in this argument tangential to the use of one-way methods of communication is how scientists and their institutional employers perceive or envisage science communication. Currently, from a university perspective, science communication is often not considered part of core business, excluding corporate communication such as student recruitment, marketing, media and other targeted strategies of this nature (Jacobson, Butterill, & Goering, 2004; Poliakoff & Webb, 2007). Searle (2013) discusses how scientists are integral in the communication of science to the public, and that the factors of risk, restraint, reality and reward influence the relationship between scientists and if and how they communicate with the public. She reported on the findings of her 2011 study stating that the perception is that communication is a barrier to career progression as it takes time away from other academic activities, Searle (2013) states that

> most examples of hindrances to scientists' communication occurred within their workplace. These included a lack of time to organise, prepare, and communicate. …[in addition to] [h]eavy workloads and finding time to apply for funding grants and actually do research were necessarily a higher priority for scientists than finding time or opportunities to communicate with the general public (p. 48).

Searle (2013) proposes a remedy to this in that

> scientists need their communication with the public to be judged as equally important for performance assessment and promotion as conducting and publishing research and securing funds. This would lead to the provision of what many scientists want: more time, more opportunities, and more communication training. From this, both scientists and the public would all benefit (p. 54).

To enhance and encourage increased communication by scientists, institutions need to make undertaking science communication self-evident and straightforward. This may mean that additional specialist science communication support should be provided. Currently, there are few incentives for scientists to use other more participatory or two-way models over one-way communication. If this is the aim, then it needs to be obvious and as easy to implement as one-way communication. Until this happens there is no incentive to change and the default model will likely remain one-way communication.

The question is, is this actually a bad thing?

There are occasions where one-way methods of communication become the optimum model of choice, including when resources are constrained, understanding fixed messages, and with risk and crisis communication.

One attraction of one-way methods of communication is that they are typically less resource intensive, in terms of time, money and materials than the more inclusive participatory models of science communication (Lewenstein, 2003b). Often science communication activities are a compromise between what is the most effective communication model and what is affordable (Barnett, et al., 2010). One-way methods of communication are attractive for not only communicating a pre-determined or specific message to the public, but also as a method that is easily scalable for very large audiences (Gage et al., 2013; Lewenstein, 2003b; Van der Auweraert, 2004), and whose appeal lies partly in 'seduction by reduction' (Wright & Nerlich, 2006). One-way methods of communication are straightforward to use, making them the model of choice for inexperienced communicators or those dealing with a limited time or money, or fixed message (Dobos, Orthia, & Lamberts, 2014; Lewenstein, 2003b; Van der Auweraert, 2004; Wright & Nerlich, 2006).

The one-way communication of fixed messages, such as public lectures, media broadcasts, newspaper articles or brochures is less resource intensive not only to undertake, but also to evaluate. The communication of a pre-determined or fixed message sets a baseline for evaluation making these one-way communication activities easier to evaluate, and measure the public's understanding and retention, than unstructured activities such as museum visits or dialogue events (Falk, Dierking, & Boyd, 1992; Gammon & Burch, 2007; Metcalfe & Perry, 2011; Rennie, 2001; Serrell, 1996).

The communication of fixed messages is the primary attribute of one-way methods of communication. While the relevant merits of differing communication models and their evolution have been discussed earlier, it is evident that there remains a need to communicate in such as way as to increase the understanding of the receiver or to communicate a fixed message. In these situations the ideal method of communication is one-way (Van der Auweraert, 2004).

Van der Auweraert (2004) briefly discusses the policy shift from one-way communication towards two-way communication, investigating the impact on science communication outcomes and the associated models. As an outcome she proposes a framework for science communication comprised of the concepts of understanding, awareness, engagement and participation, as well as their respective methods, models and driving forces. She states that if the goal is to achieve an understanding through science communication, then the one-way dissemination of information is the most appropriate model; just as if the goal is to achieve broader public participation then the most appropriate model for communication would be dialogue or bottom-up communication driven by public demand (2004). While the sentiment around 'understanding' is consistent with a deficit model view of the public, Van der Auweraert is motivated by the desire to communicate a fixed message to increase understanding on a particular topic, rather than having the attitude or belief that there is a deficit public that needs to be educated into properly scientific attitudes. It is the motivation behind the activity that is paramount in ensuring that the use of one-way methods of communication is not a reinstatement of the deficit model. Accordingly, Van der Auweraert's science communication motives are more in line with the traditional science literacy movement, though according to Wynne (2008) this and the deficit model are just different variations on the same theme.

The communication of fixed messages is often seen in risk and crisis communication, a key example of one-way communication in practice. There are many different facets to risk and crisis communication; broadly speaking, the purpose of risk and crisis communication is to disseminate information from the informed to the lay receiver. Risk communication differs from crisis communication in terms of the immediacy of the threat. Risk communication is information and warning of a *potential* threat. Crisis communication is information and practical advice on what to do next as the result of an *imminent or current* threat (Lundgren & McMakin, 2009; Telg, 2010). Risk and crisis communication are not necessarily mutually exclusive, with risk communication often preceding crisis communication depending on how the particular situation develops (Telg, 2010).

Typically, risk communication involves passive information transfer that is not time critical or imminently life threatening (Telg, 2010). For example, if you live in a tsunami prone area the local council would communicate the risks to the population potentially through information brochures or warning signs. Risk communication occurs constantly and is everywhere. In the last 25 years there have been a number of major, nation-wide, government-funded risk communication campaigns. In the UK, examples include communication about GM food and BSE epidemic, which had the unintended consequence of increasing negative public attitudes towards science, and invoked, with respect to the BSE epidemic, crisis communication (Frewer & Salter, 2002).

Crisis communication commonly involves emergency situations that are time sensitive and potentially life threatening (Lundgren & McMakin, 2009; Telg, 2010). For example, the 2011 Japanese earthquake, tsunami and the resulting Fukushima nuclear reactor disaster or the 2009 Influenza A (H1N1) ‘Swine Flu’ pandemic are two examples of recent crises that had immediate and far reaching impact requiring urgent intervention and action. In these situations crisis communication methodologies were required to disseminate factual information and instructions to the public in a time sensitive, even immediate, manner (Gage, et al., 2013; Telg, 2010; Wright & Nerlich, 2006). In these situations that one-way methods of communication are the most effective (Gage, et al., 2013; Wright & Nerlich, 2006).

Risk communication is often nuanced. As risk is inherent in all actions and activities, what is of significance in risk communication is the perceived size of the impact of the potential threat. Scholars Trench and Wynne examine risk from an authoritative perspective, presenting two different views on risk communication and the potential impact of risk. Trench (2008) seeks to classify risk communication in terms of potential impact on the public by analysing how various stakeholders rank risks differently. In this effort to standardise and guide risk communication Trench reports on the following formula that was developed by the earlier work of Sandman: risk = hazard (factual scientific evidence) + outrage (perceived severity of public response) (Sandman, 1987). It is believed that this combination of hazard and outrage provides a useful measure for communicators, typically the media, in their assessments and understanding of potential impacts (Sandman, 1987; Trench, 2008). Wynne (2008), on the other hand, discusses the matter of risk from an institutional perspective, as the only form of public concern recognised by policy insitutions. He argues that the reluctance or inability for the public’s concerns to be heard by government or scientific institutions only emphasises that they hold a deficit model mentality about the public’s ignorance. Lach and Sanford (2009) share a similar view when discussing risk communication regarding emergent technology. The primary example is the public debate over GM food in the UK.

While the use of one-way methods in risk communication is widely accepted, there are some scholars who seek to move beyond the traditional methods of risk communication to ones that allow for the public’s interpretation of the disseminated information to be conveyed back to the originating source (Bauer & Gaskell, 1999; Frewer et al., 2003). In these situations, the proposed methods of risk communication remains that of one-way communication, but with the addition of a feedback loop.

Current ‘best practice’ in science communication advocates the inclusion of formal feedback mechanisms, as discussed earlier in Chapters 1 and 2. Recent changes in science communication now stipulate that direct feedback from the public is a favourable requirement, yet past activities have not been devoid of an informal and often uncoordinated public response. While an uncoordinated public response may be difficult for the original sender to distil and manage, it remains effective in voicing strong public opinion. The UK's GM debate is an example of public response being effective, as both scientists and government heard the public's views; it was so effective that it has altered government policy and has impacted future scientific research agendas (BBC News, 1999; Irwin, 2006). The UK's GM debate is a prime example of the power and reach of the public voice, and has played a pivotal role in the formation of the modern era of science communication and the importance, to scientific research and government policy, of the benefits of early 'engagement' with the public with emergent technology and effective risk communication.

The mass media played a pivotal role in the UK's GM debate (BBC News, 1999). There is no other mechanism as widespread, topical and responsive to the changing environment as the mass media (Donovan & Carter, 2003; Lee & Scheufele, 2006). The public relies heavily on mass media as their main source of information, doubly so in times of crisis when information is at a premium (Lee & Scheufele, 2006; Rundgren, Rundgren, Tseng, Lin, & Chang, 2012; Wright & Nerlich, 2006; Yang & Kahlor, 2013). In this sense, it can be argued that the mass media is the foremost example of effective one-way communication.

Since the beginning of mass communication through the printed press, radio, television, the internet and now social media, the question of whether these communication mechanisms are one-way or two-way has been widely debated (Hongcharu, 2009; Kung, Picard, & Towse, 2008). Ratings, sales and letters to the editor can all act as a delayed two-way feedback loop to the sender (Baran & Davis, 2012), but commonly the literature implies that mass media is a one-way method of communication, typically using a one-to-many method of dissemination of information (Curtis, 2011; Duhe, 2007; Hongcharu, 2009; Kung, et al., 2008). The exceptions here are new media and social media; which can appear to be both one-way and two-way methods of communication as they can take the form of one-to-one, one-to-many and many-to-one with or without a reply (Duhe, 2007; Hongcharu, 2009; Kung, et al., 2008) or as Hunt and Grunig (1994) define it as a two-way asymmetric model as opposed to dialogue models and alike which is considered to be two-way symmetric.

Dickson (2000) reflects on the role of the media commenting on the 'shortcomings of the narrow role into which some people attempt to channel the media in the "public understanding of science" debate' (p. 921). Dickson goes onto remark that the mass media are commonly seen, by the 'scientific community and corporate sector', as the 'conduit through which "rational discourse" can be transmitted from the scientific community to the public' (p. 921). Trench presents an alternative view reporting on an argument by McQuail who states that 'in the early days of communication research the audience was conceptualised as the body of receivers of messages at the end of a linear process of information transmission' (McQuail, 1997, as quoted in Trench, 2008, p. 5). McQuail claims that since then the 'communication process itself has been reconceptualised as essentially consultative, interactive, and transactional' (McQuail, 1997, as quoted in Trench, 2008, p. 5). This suggests that although the mechanism remains the same one-way model, it is the attitudes and actions behind the reconceptualisation of the mass media that make it appear on some levels to be more of a reciprocal communication process. There is broad agreement by scholars over the importance of the mass media as a useful tool for improving the public's relationship with science through effective journalism (Dickson, 2005; Kua, Reder, & Grossel, 2004; Lee & Scheufele, 2006; Wright & Nerlich, 2006), that values the importance of access to *factual* information as a key feature in empowering the public. Dickson (2005, para. 8) states that 'both journalists and other types of science communicator face the task of providing individuals with the facts that empower them to engage properly in such dialogue'.

The mass media have a special role in the communication of science as they are the primary source of information for adults post formal schooling (Lee & Scheufele, 2006; J. D. Miller, 2004; Rundgren, et al., 2012; Yang & Kahlor, 2013), with newspapers being the most common form of old media written communication (Kua, et al., 2004). It is no surprise that the mass media play a significant role in influencing public decision making and behavioural change (Donovan & Carter, 2003), as well as in political discourse and policy decision making (Dickson, 2005) and influencing public opinion through targeted journalism (Dickson, 2005; Sturgis & Allum, 2004). They are of course subject to bias and external influence through the exercise of ownership and advertising preferences, yet remain a powerful mechanism used to influence the masses where a hostile public and media can have serious impact on scientific research programs (Sturgis & Allum, 2004).

In short, much of the literature suggests that there are legitimate roles for one-way communication in public discourse about science, whether that is because of unavoidable resource constraints or an uncontroversial utility of such approaches. Despite the disavowal of one-way methods of communication by some scholars it is evident that they remain a useful and efficient mechanism in science communication and in achieving the goals of a scientifically engaged Australia.

Is there a legitimate role for the deficit model thinking about the non-scientist public?

This section presents emergent themes from the academic literature that address the deficit model's persistence and reinvention; its complex relationship with knowledge transfer as an aim of science communication initiatives; its support from within the scientific community; a reflection on its present status as a model of science communication; and its use in risk and crisis communications. It will also introduce the notion of 'mixed model' communication that retains the deficit model as part of a suite of communication models.

Some science communication practitioners and policy leaders see one of the primary aims of science communication originally associated with the deficit model is to generate a public that is capable of participating usefully in democratic decision making, and that actively participates in open political and scientific debate. This in turn will enhance the public's relationship with both science and politics. Yet not all scholars are supportive of the public's participation. Taverne in his 2004 conversation piece draws a relationship between science communication and public art. In discussing the role of the 'public' in greater 'upstream' development of science, he criticises what he calls the 'no practical uses' policy towards scientific development that stipulates that there must be practical research outcomes to scientific development, and also what he sees as the over-involvement of small interest groups in driving scientific agendas. Taverne (2004) argues in support of the separation of science, politics and the public, arguing that 'the fact is that science, like art, is not a democratic activity. You do not decide by referendum whether the earth goes round the sun' (p. 271). Taverne (2004) cautions against is the 'over-involvement' of the public in policy and agenda setting for science while acknowledging that 'of course openness and transparency should be encouraged where possible' (p. 271).

Despite Taverne's concerns, enhancing the publics' ability to participate in democratic decision making remains an attractive aim of some science communication agendas. To achieve this some scholars assert that knowledge becomes important, in situations where effective, reliable, accessible information is an essential prerequisite (Bodmer, 2010; Dickson, 2005), as 'how can there be the dialogue…without some understanding of the scientific issues involved?' (Bodmer, 2010, para. 32). Not all scholars share this view. It is of note that both Dickson and Bodmer are advocates for deficit-like aims; Bodmer is one of the original proponents of PUS and Dickson (2005) emphasises the importance of factual reporting by journalists. Dickson (2005) outlines that the solution to effective dialogue and participation with the public is to empower the public by creating an informed citizenry through mass communication, focussing on the role of the media and journalists in communication and the importance of quality and factual reporting. Dickson asserts that 'substantial and effective dialogue will only take place when those on both sides have a sound understanding of the relevant factual evidence; indeed evidence-based decision-making is an ideal that we should aspire to' (Dickson, 2005, para. 9). Dickson continues his remarks on the persistence of the deficit model, stating that

> [t]hose who came up with this argument were entirely correct in pointing out that this type of thinking, combined with the desire to overcome public scepticism, motivated much of the early public understanding of science movement — and indeed continues to do so in many parts of both the developed and the developing world (2005, para. 12).

The persistence of the desire for increased knowledge in the public is a particularly common theme present in the academic literature.

Irrespective of modern science communication aims of participation and dialogue, knowledge continues to reassert itself as a primary motivator of science communication and remains central to its scholarship. Knowledge in its crudest form is a key feature of all science communication, but has particular ties to both the deficit model and PUS era of science communication. Trench (2008) discusses and is critical of the motivations behind the science communication movement being based on the desire to secure the nation's knowledge economy against the projected future shortfall of scientifically literate people. Trench (2008) reflects on recent changes reporting that it appears that the motivation to create a scientifically literate public remains, yet is now focussed on addressing the public's deficit in attitude towards science – a reinvention of the 'supposedly discarded deficit model of science communication' (p. 8).

While the relationships between knowledge and attitudes have been widely debated, some evidence suggests an increase in knowledge results in an increase in positive attitudes towards science (Bauer, et al., 2007, p. 84). Some studies have found 'significant and positive associations between knowledge and engagement with biotechnology' (Sturgis, Brunton-Smith, & Fife-Schaw, 2008, p. 167). A study by Sturgis and Allum (2004) explores the relationship between knowledge and the formation of public attitudes and the effect of context, in this case political knowledge, through a survey of the public. The survey found that people with a greater understanding of politics and greater scientific knowledge had more a positive attitude towards science than those who had a high level of scientific knowledge but a low understanding of politics (Sturgis & Allum, 2004). Sturgis and Allum (2004) go on to state that

> the simple logic of the deficit model was supported by a good deal of cross-national empirical evidence for a robust but not especially strong positive correlation between 'textbook' scientific knowledge and favourability of attitude toward science (p. 57).

In this context, the authors argue in support of the deficit model stating that they feel that scrapping of the deficit model entirely is not warranted (Sturgis & Allum, 2004). They go onto discuss a number of cultural, economic, social and political values that influence the public's trust, risk perception and worldviews, which influence the public's attitudes toward science. However, there is no reason to assume that scientific knowledge does not have an independent effect on the formation of attitudes (Sturgis & Allum, 2004).

The 'positive relationship between knowledge and attitudes seems to hold only for "general" attitudes about science' (Gauchat, 2011, p. 754). Some scholars have identified that information provided through the media with the aim of increasing knowledge can alter the public's attitudes and health behaviours (Australian Public Service Commission, 2007; Gage, et al., 2013; National Institute of Clinical Studies, 2003; Sarah E. Gollust, Paula M. Lantz, & Ubel, 2009). Others have found 'little evidence of attitude change as a function of information provision' (Sturgis, et al., 2008, pp. 166-167), and that education is positively correlated with ambivalence towards genetic testing (Sjöberg, 2014) and vaccination (Deady & Thornton, 2005). While there is not enough evidence present in the literature to draw a firm conclusion, overall the science communication literature suggests that generally an increase in scientific knowledge has a slight correlation with an increase in positive attitudes toward science some of the time.

The deficit model's ambition of increasing the public's understanding is achievable with the strategic use of contextual information; as context can be used to enhance learning outcomes. Studies have shown that non-scientifically trained members of the public do have the capacity for understanding complex scientific information when it is in context or directly related to their situation (Kua, et al., 2004; Lach & Sanford, 2009; Lewenstein, 2003b). For example, 'research has shown that in communities with water quality problems, even people with limited education can quickly come to understand highly complex technical information' (Fessenden-Raden, 1987 as quoted in Lewenstein, 2003b, pg. 2). To maximise the outcomes 'an adequate model of public understanding [of science] must be based on a view of science as a human and socially located activity, recognising that knowledge only becomes meaningful and identifiable as such in relation to context' (Locke, 2002, p. 93). By placing new knowledge in context it enhances understanding, which in turn can have positive flow-on effects in relation to the public's attitudes towards science (Lewenstein, 2003b; Sturgis & Allum, 2004).

Blackman and Benson (2012) discuss the creation, transfer and dissemination of knowledge between scientists and the lay public, outlining why effective knowledge transfer is so important to the creation of shared understandings by increasing the publics' scientific literacy. Lederman shares a similar view to Blackman and Benson, of the importance of the public's understanding, but from a different perspective as he states that 'there must be a major increase in the capability of ordinary people to cope with the scientific and technological culture that is shaping their lives and the lives of their children' (2008, para. 4).

While much of Dickson's commentary is in favour of the persistence of the deficit model, he believes that to achieve the goal of effective dialogue between science and the public, the public is required to already have a sufficient understanding of science. Dickson remarks that, as the '17th century philosopher of science Francis Bacon expressed it, *"knowledge is power*" (with its corollary that a lack of knowledge leads to a lack of power)'(2005, para. 18). Dickson firmly believes that journalists are key to empowering the public through the supply of accurate and reliable scientific and technological knowledge in an accessible way, and that 'filling the relevant "knowledge deficit" - is an essential prerequisite of both healthy dialogue and effective decision-making' (2005, para. 29). Not all scholars agree with Dickson, yet some share similar views. Irwin (2006) attests that in 'the heart of the "new" reside some very "old" assumptions', in that despite efforts to the contrary, knowledge remains a motivator, in this instance to enhance public trust and governance over science (p. 304). Unlike Dickson, Blackman and Benson (2012) suggest the use of peer communication as opposed to journalism, and that the public's capacity and understanding would be 'increased through the use of volunteers who would then disseminate such knowledge to their peers and into the wider community' (p. 574).

The desire for knowledge transfer is evident throughout the literature; not all authors share the same opinions, yet there is general consensus amongst scholars that 'the deficit model thinking remains prevalent' (Besley & Tanner, 2011, p. 239). Mellor provides a summary of a discussion at the International Network on Public Communication of Science and Technology (PCST) in 2008, which focussed on three distinct approaches to science communication – deficit model, dialogue, and participation – and how they differ from each other in methods and ideological bases. Mellor (2008) reports that while the deficit model has been widely criticised, it was 'noted that nearly all communication is founded on a deficit of some sort' (para. 5) and that the discussion at the conference provided evidence that the deficit model is 'indeed alive and kicking' (para. 7). From this discussion, Mellor raises the question about the differing motivations behind communication methods and what public engagement is meant to achieve that is different from the ideological ends of the deficit model. Her comments are limited to a report on conference discussion however she aptly identifies ambiguity surrounding communication models and highlights the persistence of the deficit model within the science communication environment. Others provide evidence as to the persistence of the deficit model such as Irwin and Michael (2003), Lewenstein and Brossard (2006), Sturgis and Allum (2004), Wilsdon, et al. (2005), Dickson (2005), Wynne (2006), Bauer, et al. (2007), Trench (2008), Besley and Tanner (2011) and Lewenstein (2003a, 2003b); Stocklmayer (2013).

The deficit model's persistence can be in part be attributed to its reinvention. Trench (2008) is one of the main proponents of the notion of its reinvention as he discusses the persistence and 'multifold reinventions of the deficit model' (p. 2), arguing that even though the vocabulary has changed, the underlying assumptions remain, as now the focus is no longer based on the educating the 'ignorant' public but rather on educating them into 'scientifically' proper attitudes (Sturgis & Allum, 2004; Trench, 2008; Wynne, 2006). Courvoisier, et al. (2013) share this view, highlighting an instance of reinvention in action in their critique of the contextual model of communication as defined by Lewenstein (2003b). They state that although Lewenstein's 'approach acknowledges the importance of anchoring factors in the reception of scientific information, it remains a sophisticated version of the deficiency model, as it does not challenge the conception of the public understanding of science as a fundamentally problematic concern' (Courvoisier, et al., 2013, p. 3). Wilsdon, et al. (2005) provide further evidence that 'old assumptions continually reassert themselves' (p. 18) through the persistence of the deficit model under the guise of current 'participatory models' of communication. They elaborate on this, discussing the comments made by Lord Alec Broers at the 2005 Reith Lectures in which he reiterated that there needs to be a move away from the old concept of the PUS to the more dynamic public engagement models. Shortly afterwards he was quoted as saying to Baroness Warnock, in response to her statement about the incoming government needing to build nuclear reactors, 'I agree with you. But I don't know how quickly we can educate the public, to bring evidence forward in a calm and rational way' (quoted in Wilsdon, et al., 2005, p. 19). This statement by Lord Broers highlights the persistence of the deficit model of thinking about the public under the guise of 'participatory models' of communication.

Other scholars provide evidence as to the deficit model and the need for knowledge transfer remaining active within current public engagement initiatives (Barnett, et al., 2010; Jensen, 2010; Neresini & Bucchi, 2011; Wynne, 2006). Weigold (2001) discusses the complex relationship between scientists, journalists and the public, commenting on their disparate communication objectives:

> [t]he scientist's primary responsibilities are to disseminate information, educate the public, be scientifically accurate, not lose face before colleagues, get some public credit for years of research, repay the tax-payers who supported the research, and break out of the ivory tower for the sheer fun of it. The journalist's goals are to get the news, inform, entertain, not to lose face before his or her colleagues, fill space or time, and not be repetitive (p. 181).

Weigold's reflections highlight the persistence of the motivation by both scientists and journalists to inform the public. Jensen's 2011 study reflects on Weigold's 2001 paper, emphasising the organisational perspective by stating that 'in a more official environment, the strongest reason given to justify public engagement is "informing the public," again a classical result of the deficit model' (Jensen, 2010, p. 35). Barnett et al. (2010) report that 'the communication of information was central [to the interviewees – participants from in the renewable energy industry] even where ostensibly the focus was on consultation or other more two-way engagement processes', contravening current science communication 'best practice' because 'the focus on information provision thus seems to preclude consideration of a model of engagement that involved an early exchange of views' (p. 42). The emphasis on information provision and informing the public is apparent in other studies; some scholars such as Watermeyer (2012) see the transmission of knowledge as a desirable outcome of public engagement. Others contend that the 'concepts themselves of "success" and "positive outcome" appear ill-defined when it comes to public engagement owing to either too narrow and functional, deficit-like visions of the aims of PE or the difficulty of accommodating the different objectives of the actors [practitioners] involved in the process (Neresini & Bucchi, 2011, p. 66). Wynne (2006) comments on the persistence of the deficit model, remarking that the practices of public engagement fall short of what is anticipated and that

> [f]or all their fashion-following language of upstream public engagement, they remain rooted in attention only to downstream impacts, and not to making upstream driving purposes, about the human ends of knowledge, not only its instrumental consequences, more accountable and humane (pp. 217-218).

The use of 'engaging' models of communication to deliver on aims associated with the PUS era and the deficit model view of the public is again highlighted in a scenario similar to Lord Broers and the nuclear debate in the form of the 2003 'GM Nation' debate in the UK. In response to the debate's findings there was an attack by policy makers on the processes and protocol for allowing environmental groups to have too much influence, in which they concluded that further dialogue was needed until the public had the 'right' attitude (Bauer, et al., 2007; Irwin, 2006, 2008; Taverne, 2004). This behaviour provides evidence as to the persistent view that the public is deficient, in this case referencing their attitudes toward GM food, and need to listen and change. This account provides a text-book case of the traditional deficit model attitude.

It is not only politicians and policy makers: scientists also tend to view 'engagement' with the public as being chiefly about dissemination of information and one-way communication rather than participation or dialogue (Besley & Nisbet, 2013; Davies, 2008). Kreimer, Levin, and Jensen (2011) found that

> senior and junior academic scientists do not carry out the same type of popularization activities. Prestigious activities such as interviews on television or in newspapers are more frequent among senior scientists, while junior researchers are more active in less prestigious activities like open doors [public lectures] or school talks (p. 45).

Attitudes to communication based on seniority was also discussed by Searle (2013) who found that communication with the public 'varies with their [the scientist's] age and seniority. Those who are paid to communicate with the public as part of their job are more likely to be older scientists in more senior positions' (p. 47).

The methods of communication presented here are predominantly one-way, and based on hierarchy and kudos where senior staff, who generally hold a deficit view of the public, are involved in the more prestigious and far reaching activities, such as mainstream media (Kreimer, et al., 2011; Searle, 2013). The authors report on the dominance of one-way communication activities in practice, a view that is supported by the findings of the 2012 study into Australian science communication activities by Metcalfe et al. This study also revealed that in practice, scientists are the primary practitioners of science communication; while many science communication activities are undertaken or managed by professional science communication practitioners, scientists are still responsible for much of the active science communication whether it is self-motivated or otherwise, including fact checking for science communicators (Metcalfe, et al., 2012). As the primary participants in the communication process it is important to understand how scientists view science communication activities, noting that unlike science communication practitioners scientists commonly maintain a deficit view of the public (Dickson, 2005; Metcalfe, et al., 2012; Siipi & Ahteensuu, 2011; Sturgis & Allum, 2004; Wynne, 2006).

A focus group study by Davies (2008) discusses the motivations behind science communication activities to better understand how scientists perceive what science communication involves. Again the findings indicate that scientists still hold a deficit model view of the public. Davies reports that the scientists believe that as a result of 'education' the public will have a greater understanding of science, be inspired with a greater interest in and a more positive attitude towards science, and that there will be enhanced recruitment into studying and working within the sciences. Davies' study highlights the diversity of ideas about public communication in scientific cultures, and that there is not one straightforward notion of what is involved. The scientists in her study do not consider that the public has a voice in the communication process, but rather communication is constructed around what scientists have to say. The focus group discussion revealed that it is now generally acknowledged by scientists that it is important to make communication relevant to the public and that it is better to communicate 'big ideas' or key principles rather than detailed research.

Other scholars present similar views to Davies in their discussions over the scientific community's views towards the public. The scientific community remains motivated by the desire to achieve a better-educated public with a more positive attitude to science, leading towards improved (from the perspective of scientists and policy makers) risk perceptions, policy preferences and decision making by the public (Besley & Nisbet, 2013; Davies, 2008).

The literature presents varied commentary on how scientists see the public: Besley and Nisbit report the belief that the public has a limited capacity for understanding scientific information (2013); Davies (2008) notes that reduced scientific literacy is considered by particular scientists as the root of opposition to new technologies. Others state that scientists believe the public is uninterested in becoming more knowledgeable (Besley & Nisbet, 2013; Burningham, Barnett, Carr, Clift, & Wehrmeyer, 2007); or that only poor scientists popularise, implying 'that scientists are still prisoners of the "diffusion model"…which ignores that disseminating knowledge means recreating it, a creative and difficult task' (Jensen, 2010, p. 34).

What is apparent from the review of the literature is that many scientists still favour the use of media and one-way models of communication as their primary communication method (Besley & Nisbet, 2013; Davies, 2008; Metcalfe, et al., 2012; Mogendorff, te Molder, Gremmen, & van Woerkum, 2012; Wynne, 2006). However, the use of one-way models of communication is not explicit. A study examining the science-society relationship with respect to scientists' discursive constructions found that while the method remains the same - a top-down approach to communication - the role scientists ascribe to themselves has changed; they 'now presented themselves no longer primarily as superior knowledge producers for society but more as actors who can best regulate the use of different kinds of knowledge if necessary or desirable' (Mogendorff, et al., 2012, p. 19). The authors remark that this model of the scientist's constructions of the science-society relationship appears to be something in between a deficit model on the one hand and a dialogue or participation model of the other:

> [o]ur model is similar to classical deficit approaches in that laypeople are conceptualised as lacking relevant knowledge and experience. It is dissimilar from deficit approaches in that informing the public is considered less important; instead, participants claim that laypeople lack the competence and experience to manage different kinds of knowledge needed to solve today's complex, societal problems (p. 20).

The authors' comments emphasise the persistence of the deficit view of the public and the need to manage public thought, in combination with two-way methods of communication.

While not all scholars share the same opinions, this discussion highlights that the rumours of the death of the deficit model have been greatly exaggerated (Wilsdon, et al., 2005). In support of this view, Wilsdon, et al. (2005) state that there 'are those who still maintain that the public are too ignorant to contribute anything useful to scientific decision making' (p. 34), highlighting the persistence of the attitude that the public is deficient and require education if they are to participate in public debate.

The deficit model often features in risk and crisis communication along with the use of one-way methods discussed earlier in this chapter. Frewer, et al. (2003) report on the outcomes of a study into how scientific experts communicate risk to the public. They identified that those charged with the communication of risk, including scientists, still subscribe to the deficit model approach that the public is incapable of understanding the complexities associated with risk and uncertainty and that communicating about uncertainty would have a negative impact on both the public's risk perceptions and on science in general. Yet, the public sees this differently, believing that the ability to conceptualise uncertainty is not the issue, what they want is more information about the scientific processes of risk analysis (Frewer, et al., 2003). Considerations of the public's deficits – or perceived lack of understanding - would enable enhanced outcomes of risk communication about emergent technology through contextualised communication (Lach & Sanford, 2009). These views are in contrast to those who believe that a public with a better understanding of scientific process and technology development would also have a better understanding of risk associated with scientific development and emergent technology (Frewer, et al., 2003; Pidgeon & Rogers-Hayden, 2007).

However, it is important to note that not all deficits in understanding are accidental. Reflecting further on the linkages between knowledge and attitudes, a study by Yang and Kahlor (2013) found that the public may choose to avoid information deliberately in order to maintain their state of uncertainty; choosing to be uninformed rather than facing potential negative information and scenarios, which is particularly relevant to risk communication. Michael (1992) made a similar point regarding lay-public choosing ignorance to maintain a positive outlook, and that it 'serves functionally to preclude panic under certain circumstances-to remain ignorant about the science ensures clarity about proper practical procedures' (p. 321). Michael's study highlights that the publics' own 'reflections upon their knowledge involve a direct consideration of self, in which they remark upon some aspect of themselves that disqualifies them from understanding science' (p. 318).

Mixed models of communication

The concept of mixed model communication is supported by some of the scholars who argue in defence of both 'old' and 'new' communication models. Mixed model communication provides a broad framework that is of practical utility to scientists and science communication practitioners. It seeks to balance the recommendations of communication best practice from the literature with the methods used in practice by those who actually do the communicating, outlining how both 'old' and 'new' models can co-exist when the choices about their use and communication goals are made explicit (Lewenstein, 2003b; Lewenstein & Brossard, 2006;

Trench, 2008). Lewenstein (2006b) is the main proponent of this cause, arguing that the deficit model and one-way methods have a legitimate role in science communication. He remarks on personal communication with Steve Miller (1 May 2003), stating that:

> the value of the deficit model can be rehabilitated by a shift from the 'moral pressure/you have to know this' approach to a 'softer/you might want to know this' approach (p. 6).

Lewenstein identifies a changed deficit model of the public, one where the focus is shifted to information provision that is relevant, in context and will be of interest to the specified audience, a view shared by scholars Locke (2002) and Sturgis and Allum (2004).

Lewenstein's (2003b) report establishes the initial argument for the retention of both the deficit model and one-way methods through the notion of mixed model communication. He argues that the existing models of communication are valid in their own way; however when used in isolation do not address the multiple overlapping goals of communication activities. A later study by Lewenstein and Brossard (2006) builds on the broad principles established in the 2003 report. Here the authors undertake a critical review of the science communication activities of the US Department of Energy, outlining the four key models of science communication: the deficit model, contextual model, lay expertise model, and public participation model. The authors discuss the definition of the deficit model as the belief by scholars that there is a 'deficit of knowledge that must be filled, with a presumption that after fixing the deficit, everything will be "better" (whatever that might mean)' (p. 5). Lewenstein and Brossard expand on this definition describing the deficit model as having three components:

1. Linear transmission of information from experts to the public
2. Belief that good transmission of information leads to reduced "deficit" in knowledge
3. Belief that reduced deficit leads to better decisions about science, and often better support for science (p. 40).

The analysis of their key models of science communication highlighted that 'theoretical approaches to public communication of science do not capture the complexity of the reality of informal science education projects' (Lewenstein & Brossard, 2006, p. 39). Lewenstein and Brossard's study found that in reality

> the deficit model of public communication of science seems to be, whatever the context, an overarching framework for outreach…[and that] the 'deficit' approach showed some overlap with the 'engagement' model, if engagement is conceptualised as 'empowerment' of the readers (p. 38).

As an outcome of this study Lewenstein and Brossard state that '[o]utreach projects have all a "Deficit Model" approach as a backbone, even if they seem to follow other theoretical approaches' (p. 39). They propose a new model where the deficit model and hence one-way methods form a backbone to all communication practices, underpinning the more inclusive models of communication: contextualist, lay knowledge and public engagement. Bonfil Olivera (2004) discusses Lewenstein's (2003b) proposed four models of public communication with reference to his own experiences, arguing that 'it is clear in Mexico, as in many other countries, the [traditional] "deficit" model is prevailing, with the "context" model slowly gaining recognition' (Bonfil Olivera, 2004, p. 2). He reinforces Lewenstein's argument in support of differing models of communication, stating that 'all four of Lewenstein's models can be useful in certain circumstances, and none has necessarily to be discarded in favour of the others' (Bonfil Olivera, 2004, p. 2).

Trench (2008) expands on this argument stating that when considering the relationship between one-way and dialogue there are circumstances where the 'old' ways of one-way communication can have a legitimate place. Like Lewenstein, rather than focussing on the stark differences between communication models, Trench investigates how they can complement one another. He proposes a new framework, similar to Lewenstein and Brossard's, where the reclaimed deficit model is removed from the presumptions of 'incorrigible cognitive deficiency' in the public and the assumption that more knowledge about science would mean greater appreciation or support for science (Trench, 2008, p. 10). Trench adopts a description of the deficit model as 'as one-way communication from experts with knowledge to publics without it; it is [science communication] now carried out on a 'dialogue model' that engages publics in two-way communication and draws on their own information and experiences' (p. 1) in his reflection of the evolution of science communication.

Trench (2008) points 'to the very evident persistence of the deficit model' (p. 2) as he states that 'the deficit model survives as the effective underpinning of much science communication [and that] a legitimate case can be made for the retention of a dissemination model in certain circumstances' (p. 10), a view shared by others including (Dickson, 2000, 2005), Wright and Nerlich (2006). Trench (2008) goes on to state that 'the supposed shift from deficit to dialogue has not been comprehensive; nor is it irreversible' (p. 4), adding a remark made by Peters that 'the rehabilitation of dissemination is not intended as an apology for the commissars and the bureaucrats who issue edicts without deliberation or consultation', but rather a legitimate model for communication (Peters, 2000 as quoted in Trench, 2008, p. 6). One key feature of his argument is that the deficit model he describes has no aims of measurable outcomes, focussing instead on the process of participation (Trench, 2008).

Stocklmayer also addresses the topic of mixed model communication in a 2013 chapter. She presents a new perspective on science communication models, proposing a framework based on a continuum of science communication in an effort to examine and classify science communication activities in terms of purpose. This framework forms a 'spectrum of models': at one end is the promotion of science through 'one-way transmission which intends only to inform…at the other end, there is knowledge building, a process that seeks to construct new meaning from many contributions' using multi-way communication models (Stocklmayer, 2013, p. 23). In the middle between these two is knowledge sharing in the form of dialogue, a two-way communication model. Stocklmayer (2013) constructs her model using basic questions about the following three communication aspects: '(1) who communicates the science; (2) to or with whom does the communication occur; and (3) with what purpose?'(p. 31). This communication model uses the Zwicky method, a simple multi-celled cube, useful in investigating boundary conditions. Each cell of this matrix identifies the proposed science communication models for each particular combination of circumstances as defined by the three aspects, forming a matrix of science communication activities satisfying the overarching parameters.

As part of this model Stocklmayer discusses the benefits of, and proposes the retention of, one-way methods of communication. This model outlines the beginnings of the formation of a useful framework for selecting the correct communication model to satisfy particular communication agendas. However, science communicators have yet to imagine all the approaches to communication that might fill the Zwicky cubes, but this model moves us some way towards a new approach to theorising about communication methods.

Mixed model communication legitimises the retention of both the deficit model and one-way methods of communication by illustrating how different models serve different communication purposes. Scholars agree that in a mixed model communication framework the deficit model and one-way methods underpin the subset of more inclusive methods of participation, dialogue, contextual and lay expertise models. Many scholars support the use of diverse science communication models to satisfy communication goals, where the models are used to complement one another rather than compete (Bonfil Olivera, 2004; Lewenstein & Brossard, 2006; Sturgis & Allum, 2004; Trench, 2008; Van der Auweraert, 2004; Wright & Nerlich, 2006).

This review highlights that the deficit model and one-way communication are still persistent in the modern science communication era. This discussion identifies the strengths of these models and provides evidence towards the benefits of their retention. In particular one-way methods of communication, when separated from the discussion from the deficit model, were identified as ideal models in circumstances that require the communication of fixed messages, in risk and crisis communication, when resources are limited, and in the most common form of public communication – the mass media. These models have not been absolved from their past indiscretions and associations, but rather they have been reimagined and redefined to include elements of context and audience consideration, and can be used in conjunction with two-way models of communication under the guise of mixed methods of science communication.

The special edition issue of the Public Understanding of Science journal reviewed as part of the discussion in chapter 2 is of relevance in framing the discussion here on the reality of the practice of science communication. The discussion in this journal highlights a disconnect between the practical day-to-day science communication practitioners and the science communication scholars that exists with respect to undertaking PE activities (Besley & Tanner, 2011; Chilvers, 2013; S. Miller, 2008). Scholars argue that this disconnect between practitioners and scholars is often problematic (Chilvers, 2013). Often the strategies used by the engagement practitioners do not match their stated goals, appearing to be ill suited to achieve the desired outcomes (Powell & Colin, 2008). This disconnect is compounded when adding in scientists and policy makers into the mix (Allspaw, 2004). Scholars argue that it becomes important to 'mind the gap' between the theoretical ideal of PE and the realities of implementation and practice (Delgado et al., 2011; Irwin, 2001; Wynne, 2006). Other scholars suggest that some practitioners simply go through the motions of PE without actually undertaking 'true PE', either in order to say that they have done the right thing or to placate the public as a consulted public is often more supportive (Rowe & Frewer, 2000, 2004).

In this special edition publication, many authors comment on the discrepancy between the ideal as proclaimed by the academic literature and the reality of science communication in practice. There has been a shift in the rhetoric over the last 20 years from PUS and deficit model thinking to PE, however 'as the participatory movement attempts the awkward transition from high theory to complex and messy practice, a number of dilemmas are encountered which problematise the notion of public engagement' (Sturgis, 2014, p. 38). The question has been raised whether PE has been able to 'live up to the theoretical tenets of deliberative and participatory democracy upon which they are founded; and whether citizens actually favour direct participatory approaches as the mode of science governance' (Sturgis, 2014, pp. 38-39). Furthermore, Irwin in his comment on this special edition states that all the 'contributors draw our attention both to the sometimes-enormous gap between the easy rhetoric of engagement and institutional practice, and to the disjunctures, erroneous assumptions and tensions in the very definition of 'public engagement with science' (2014, p. 75), a sentiment shared by others (Bauer, 2014; Stilgoe et al., 2014; Sturgis, 2014).

Case studies into the reality of communicating science

The ongoing use of the deficit model of the public and one-way methods is apparent in the following four case studies that present real-world examples of science communication in practice. The inclusion of the first three case studies was determined based on the fact that they were the only examples in the formal science communication literature post 1999 that report on deficit or one-way communication activities in practice. Each case study is unique as it presents a different view of science communication in practice. Not all authors share the same opinions. Some support the use of these models by direct statements such 'the deficit model is an important part of a culture of argumentation *shared* by both scientists and members of the public, and drawn upon as explanations of the public understanding of science' (Wright & Nerlich, 2006, p. 331). For others support is implied in the use of one-way methods of communication (Arcand & Watzke, 2011; Naylor & Keogh, 1999). The fourth case study is a detailed account of a commissioned project carried out by the author. It is a hitherto unpublished description of a project in which multiple stakeholders informed the outcomes and is therefore described from conception to completion. This project used one-way methods of communication, as it was the most appropriate model in order to satisfy the multiple stakeholders' communication requirements.

In spite of the shortcomings of the PUS era and the communication models of that time, what is apparent from the review of the literature is that there is a legitimate role for deficit model and one-way methods in communicating science.

Case study 1: use of the deficit model in a shared culture of argumentation: the case of foot and mouth science, Wright and Nerlich, 2006

Wright and Nerlich (2006) investigate the use of the deficit model in the role of 'the public understanding of the public understanding of science'. Unlike previous studies which focussed on how scientists and policymakers conceptualise the public, this study sought to investigate 'how the public understanding of science is conceived by a focus group composed of members drawn from the general public' (p. 331). The authors sought to explore the assertion that scientists and the public use the same argumentative practices with respect to the deficit model. Using the 2001 UK's foot and mouth crisis they undertook discourse analysis of a focus group debate about the science behind the spread and control of the virus. Motivated by the desire to determine whether members of the general public actively use the deficit model, their results suggested that 'the deficit model is an important part of a culture of argumentation *shared* by both scientists and members of the public, and drawn upon as explanations of the public understanding of science' (p. 331) and that the deficit model is a legitimate communication model in certain circumstances, when the aim is enhanced understanding.

Wright and Nerlich discuss the challenge of science communication to accurately describe the relationship between science and the public. They recognised that the deficit model as a description of this relationship and as a suitable communication model 'serves scientists, the public and others alike as a resource for political discourse' (p. 331) (the appeal and benefits of the deficit model is a sentiment that is supported by Bonfil Olivera (2004); Davies (2008); Lewenstein (2003b); Lewenstein and Brossard (2006); Trench (2008)). Wright and Nerlich (2006) discuss that the 'outright rejection of the deficit model in favour of "alternative" explanations of the public understanding of science overlooks the importance of the deficit model as a shared cultural resource used to discuss science' (p. 332). They argue that a key feature of the deficit model is the two-stage process of how scientists develop knowledge and subsequently communicators or mediators disseminate simpler accounts to the public. The requirement of a mediator does not necessarily imply a public deficit; rather it highlights the need for assistance for the communication activity. The authors discuss that commonly it is journalists that take on the mediator role, charged with bridging the gap between science and the public, a necessary role that is exacerbated by the fact that 'some scientists and sociologists still conceive of the deficit model as an adequate *social science* description of science and society' (p. 333).

As an outcome of this study, Wright and Nerlich state that 'a deficit in the public understanding of science is viewed [by the focus group participants] as problematic as it leaves people open to manipulation by the government and/or the media' (p. 337). This view corresponds closely to the 'traditional' conception of the deficit model that sees the public as lacking in understanding and in need of education for their own good. The focus group demonstrated that participants were interested members of the public making a personal commitment to learning more about science, and that in times of crisis 'the general public look to the so-called experts to do the expert thing because they are the experts' (p. 339). However, there is a 'limit to the cognitive ability of the public to hold "enough" knowledge of science…[and that] ignorance in science…is not bad in itself but the result of a division of labour' (p. 338).

The outcomes of this study highlighted that informed decision making is enhanced by consistent messaging to the public. The current communication environment supports blame for the 'lack of communication on the part of X, or the lack of understanding on the part of Y' (Wright & Nerlich, 2006, p. 339), where scientists, the media or the public can all be blamed for a deficit in communicating or understanding. Wright and Nerlich (2006) argued that this shows that

> the deficit model is part of a culture of argumentation in which both "sides" use a version that emphasize [sic] mismatches between knowledge and communication depending on where users locate themselves in any particular instance within science or society (p. 339).

Wright and Nerlich concluded by stating that the deficit model needs to be recognised as a 'resource used in rhetoric and debate, and whose appeal lies partly in "seduction by reduction" and the ease with which dualistic positions can be set up to construct and contest (social) science, society and the public' (p. 340). They argued that science communicators should cease to reduce the complexities of PUS to one factor – the deficit model – and advocate the use of mixed methods of science communication. In addition to providing evidence as to the persistence of the deficit model, these scholars openly acknowledge the usefulness of the deficit model, reporting that their 'results point to the importance of the deficit model in the public understanding of the public understanding of science' (p. 332), yet caution that the 'relationship between science and society needs to be looked at in ways other than in terms of "one-way communication from scientist to the public" suggested by the deficit model' (p. 340). While the scholars do not support scientists in taking a deficit model approach in their communications, they do note that it is an attractive model to use in many circumstances, but in particular when knowledge or information is a key feature of the communication activity.

Case study 2: science on the underground, Naylor and Keogh, 1999

Naylor and Keogh (1999) reported on the science communication initiative 'Science on the Underground' undertaken in March 1998. The project consisted of four posters of concept cartoons depicting everyday situations. Each character in the cartoon puts forward alternative viewpoints about the science involved in the situation. This project was designed to 'raise interest and awareness, provoke follow-up action and raise understanding of science amongst passengers' (Naylor & Keogh, 1999, p. 105) through the unique nature of the public transport system that provided 'direct access to a captive audience' (Naylor & Keogh, 1999, p. 106).

It is important to note that this project was conducted prior to the 2000 House of Lords report and formal end of the PUS era. Naylor and Keogh (1999) discuss the deficit model, explaining that

> the public's understanding of science is measured against that of the scientist and any shortfall noted [and] the flow of information is one-way only from the scientist to the public…[The deficit model] assumes that the acquisition of scientific knowledge for its own sake is worthwhile, and that the public understanding is limited by the willingness of scientists to engage in communicating their knowledge to the public or by the willingness of the media in reporting scientific ideas (p. 106).

Naylor and Keogh do go on to discuss that a weakness of the deficit model is its inability to account for the importance of context, arguing that communication models need to integrate scientific knowledge with personal values and beliefs and with situation-specific knowledge. They state that 'this process of assimilation and reconstruction is complex and problematic, with public understanding being the joint creation of scientific and context-specific knowledge' (p.106). Naylor and Keogh provide support for the use of mixed model communication as they acknowledge that while communication 'models of public involvement in scientific learning appear sharply opposed…as circumstances vary they may each have a part to play' (p. 106).

The language used in the report frequently mentions 'the learners', 'understanding', 'educate': words which are now strongly associated with PUS era. The emphasis that Naylor and Keogh place on 'learning' may be an idiosyncrasy of the time of the publication. It would be interesting to see if the same project was repeated today if the language used to describe the activity would reflect the current science communication environment of 'engagement'.

Despite being conducted in the PUS era the authors argue that this project 'avoided the use of a deficit model of science learning' (p. 119). The use of one-way methods in this project was evident; however, the authors believe that the approach used was not 'deficit model' as they did not set out to educate the public in specific scientific knowledge, but rather to stimulate deep and independent thought through context-specific one-way communication.

The authors reported that overall the project was deemed successful. Evaluation of the public impact of the posters was measured through observational survey, phone calls to the information hotline and visits to the website (Naylor & Keogh, 1999).

The 'Science on the Underground' initiative provides a good example of effective one-way communication. In this situation, having a captive audience, fixed, contextual and varied messages enhanced the outcomes of the communication activity of provoking deeper thought on scientific concepts by a broad audience, stimulated by the publics' consideration of the differing viewpoints presented on the posters. Unlike many deficit model and one-way communication activities this initiative was not designed to communicate a specific message, from an informed source to the lay public, but rather to provoke deeper thinking about science within the public by pondering the questions presented on the posters.

Case study 3: public science, Arcand and Watzke, 2011

Arcand and Watzke (2011) proposed the formalisation of an entity for science and science communication that is akin to public art for the humanities: 'public science'. They outline the view that 'public science' might be able to 'play a role in enhancing and supporting society's relationship with science through embedding science content into everyday experiences' (p. 398). Here the term 'public science' is based on the definition of public art as defined within the humanities domain as 'artwork that has been "planned and executed with the specific intention of being sited or staged in the physical public domain, usually outside and accessible to all"' (p. 399).

The authors examined one project in particular called 'From Earth to the Universe' which placed astronomy images in 'non-traditional' science communication venues such as parks, train stations, libraries and airports, as an attempt to make science accessible to non experts in public spaces, and to reach a non-self-selected audience. This project used one-way methods of communication where each image was accompanied by an explanatory body of text, akin to the CAMS communication activity (presented below) and similar to the aforementioned 1999 study by Naylor and Keogh.

Unlike the Naylor and Keogh study, the evaluation of this project was limited as the 'data collection completed by interested and self-reporting volunteer visitors' (p. 402). The authors suggested that exhibits in these settings have the potential to reach millions of people relatively inexpensively and that activities such as this can forge new partnerships between groups and organisations within the community. The anecdotal results suggest that different location types may have an impact on visitor outcomes, and can be used to forge new partnerships between communities and organisations. It was proposed that this type of communication has the ability to reach a broad audience and the nature of the content in a non-traditional setting 'can lead to inspiration, personal connections, and small learning gains' (p. 403). Overall the feedback suggests that these brief and casual encounters with science content in non-traditional settings can have a positive effect on increasing the public's exposure to science (Arcand & Watzke, 2011).

The authors' support for the one-way models of communication is not made explicit. The motivations implied in this notion of 'public science' seek to create public appreciation of science – for the value of science – not to remedy a knowledge deficit present in the public.

Case study 4: practitioner project 'Antimatter – does is Matter?'

This final, and most detailed, real world case study comes from my own experience as a science communication practitioner. The case study provides evidence that one-way communication is alive and well because stakeholders want it and they may not be concerned about engagement and dialogue with the public. In the following I reflect on and report in detail the practicalities of undertaking a science communication activity through a commissioned project which I undertook as the project manager in 2007. The project sought to communicate the science behind antimatter to the general public, and resulted in the creation of a series of 31 text-based panels exhibited at a national science centre. Describing the real life detail as I have done here provides an ethnographic perspective on how science communicators negotiate the road between theoretical ideals and practical demands, giving insight into how the practitioner world will likely shape a scientifically engaged Australia.

The primary project stakeholder was the Australian Research Council Centre of Excellence for Antimatter-Matter studies (CAMS) with its main administration and research node based at The Australian National University (ANU). Centres of Excellence have a finite lifetime in which they promote national and international collaboration through a specific focus and remit; CAMS's mission was 'to develop tools and techniques to lead Australia into a new and exciting area of research based upon positron (and electron) interactions in the physical, chemical and biological sciences' (Australian Research Council Centre of Excellence for Antimatter-Matter Studies, 2007, p. i). The research at CAMS focussed on the three broad themes of: the fundamental studies of antimatter-matter interactions and their application; positrons and electrons as probes of materials and surfaces; and positrons and electrons in medicine and biology.

This project was motivated by CAMS' desire to showcase their science and satisfy their need to increase their public visibility through an outreach activity that would produce outcomes within the finite timeframe, in order to satisfy the conditions of their funding agreement that stipulated key performance indicators relating to outreach (Australian Research Council, 2005).

The project was instigated and largely driven by the CAMS Director, Professor Stephen Buckman, who stated a personal duty and commitment to science communication and outreach on behalf of CAMS. He sought to develop an exhibit that would originally be housed at Questacon – the National Science and Technology Centre, based on the science of antimatter. As part of this Professor Buckman approached the Australian National Centre for the Public Awareness of Science (CPAS) at ANU in search of a collaborative partnership with one of their students. I joined the project in mid 2007 as the project manager leading the development of the project on behalf of CAMS and the other stakeholders. In addition to working closely with Professor Buckman, this project was developed with input primarily from the staff at the ANU node of CAMS.

The secondary project stakeholder was Questacon, an interactive science centre located in Canberra, Australia. In addition to its interactive exhibitions Questacon offers numerous other programs including but not limited to: science shows, travelling exhibitions, holiday programs, workshops, night programs and Indigenous outreach activities. While one aspect of the centre provides hands on experiences through their interactive exhibits, overall Questacon's activities are predominately one-way in that they seek to communicate pre-determined and fixed messages. The centre reaches over 3 million people annually with just under 450,000 people visiting the main exhibition centre in 2013 (Questacon, 2013), with a common audience demographic of primary school children up to adolescents and their parents, grandparents and teachers (Questacon, 2006; Yung, 2008).

Questacon temporarily housed the final exhibit, provided expert science communication and exhibit design advice throughout the project. As part of the project agreement they sought the provision of an exhibit that satisfied their aims and was appropriate for their common visitor demographic of language at a 12-15 year old reading level, with concepts that have a broad appeal including to parents and grandparents (Questacon, 2006; Yung, 2008).

Additional project stakeholders were involved to assist with specific elements of the project. Siemens, as a manufacturer of Positron Emission Tomography (PET) scanners, provided information and imagery. The Australian Nuclear Science and Technology Organisation (ANSTO), in their capacity as a research node of CAMS, provided information and imagery on nanotechnology. Relevant ANU academics and professional marketing staff provided advice on the project and some of the imagery of scientific phenomena and the CAMS laboratories.

Project development

The development of the project was guided by the following five key messages that I identified via my initial stakeholder interviews with the CAMS Director:

Key message 1: antimatter is real and has touched your life or the life of someone you know;

Key message 2:	antimatter is produced in Australia and it is used for a variety of practical applications such as in nanotechnology and in PET scanners;
Key message 3:	antimatter is a prominent feature in many science fiction stories and it is often portrayed inaccurately;
Key message 4:	an understanding of CAMS, the scientific research they conduct, and the role that their research plays in the broader community; and that
Key message 5:	CAMS is at the forefront of antimatter science in Australia playing a significantly broad role on the world stage (Buckman, 2008).

As part of the project agreement each stakeholder organisation had its own communication requirements that needed to be satisfied. The directive from CAMS was explicit in that the project needed to convey a certain level of scientific information and content and to appeal to a broad audience. CAMS sought to create an exhibit that would appeal to and challenge all visitors, from the lay public to the informed, somewhat counter to Questacon's desire for a 12-15 year old reading level. CAMS required absolute fidelity in the scientific information and terminology used – a view reinforced by ANSTO and Siemens for their respective elements. In addition, Siemens required a certain amount of scientific content specific to their interests to be communicated as part of this project.

The mismatch in the stakeholders' requirements, between wanting scientific content and terminology and wanting to appeal to the public, was apparent early in the project. In early 2008, the initial meetings with Questacon highlighted that its vision for the project was not congruent with CAMS. The major differences were in relation to the target audience, and the extent and depth of scientific content to be communicated. Questacon envisaged the exhibit to be a series of images with supporting captions; CAMS desired to create a series of text panels with supporting scientific imagery. This disconnect was managed by renegotiating the roles and responsibilities of the stakeholders. Coinciding with this renegotiation Questacon was forced to revisit their commitment to the project due to external influences and resourcing. As a result of this, Questacon's involvement in the project was reduced as they took on an advisory role providing critique in the final stages of development. As a courtesy they were asked to approve the final copy prior to production.

As the commissioned project manager I was obliged to meet the demands of the client. The tensions of the project could only be resolved by the use of one-way methods of communication as it was the most appropriate method to best suit the disparate communication objectives of the stakeholders.

Following the negotiation of stakeholder requirements the final and agreed exhibit design consisted of a series of 31 text-based panels with associated scientific images titled 'Antimatter – does it Matter?', designed to initially span the length of the central spiral shaped ramp at Questacon that visitors use to travel between floors. Appendices A, B, C and D present the details of the project development and the full set of 31 panels of the display 'Antimatter – does it Matter?' respectively.

The reality of science communication in practice is that it demands one-way methods of communication; this project shows this in action. This method of communication was optimum in meeting the requirements of the project; it enabled the specific communication objectives, including considerations of complexity and depth of content to be met. The one-way panel format created a final product that was easily transportable, and one that was less resource intensive in terms of time and money to produce.

As the project manager meeting the practical demands of the clients it was essential to understand the current communication environment with respect to past examples of antimatter science and the role of science centres and museums in communicating with the public. The following discussion presents the review of the relevant literature that framed and informed the practical development of the project, the particular decisions and design choices are further detailed in Appendices A and B. What is significant about this – and the reason for including it here – is that the bulk of the evidence-base for creating practical communication products focuses on one-way approaches to communication. Therefore, since I wanted to ensure my decisions about the project were based on best practice as described within the existing literature, I was inevitably directed towards a one-way approach. This would likely have been the case irrespective of the stakeholders' wishes.

A desktop review into past examples of communication about antimatter science was used to inform the initial project development. This review highlighted that the majority of communication had been limited to one-way methods, predominantly websites and public lectures. There was limited evidence of a few interactive displays, these however focussed on the practical applications of antimatter, including public health and information websites, not the fundamentals of the science itself (American College of Radiology, 2008; CERN, 2001a, 2001b; Manglunki, 2002; Mondardini, 2001; Pascolini & Pietroni, 2002; TRUIMF, 1998; University of Virginia Health System, 2007; WebMD, 2001).

In contrast to a typical science centre interactive standalone exhibit that requires prototype testing and demonstrates a single concept, the appeal of this one-way communication model of a 31 panel display was that it allows a large amount of complex information to be communicated, is relatively inexpensive, and fast to produce. The design was optimum for its temporary location on the main transit ramp at Questacon as it did not need to be incorporated into existing gallery space at Questacon, preventing issues of disparity between exhibits. As the project was to be initially housed at Questacon, they as a project stakeholder desired that the created work adhere to how they would describe the usual remit of the modern science centre space of 'engaging' and 'participatory' activities (Questacon, 2013a). It is important to note that this is the language used by Questacon to describe themselves outlining their aims, yet differs from the academic rhetoric. What is meant in this context is that they seek to generate interactive experiences within social visitor groups. As Questacon's requirements were secondary to that of the primary stakeholder CAMS, the developed work took the recommendations of effective science centre and museum design into consideration where practicable. Given that this was a one-way project, I made every effort to incorporate 'engaging' design features. Despite the aims of 'engagement', science centres still largely use one-way methods of communication on pre-determined subjects, or at least that was the state of the literature at the time (Lafrance, 2005; Pedretti, 2002).

It is widely accepted that science centres make science accessible to the public and encourage the excitement of discovery. Science centres have their foundation in the nineteenth century as museums housing collections of scientific and technological artefacts, materials and preserved specimens. Modern science centres now seek to enchant lay people, catalyse original scientific thought, and illustrate scientific method through hands-on experiences (Lafrance, 2005; White & Stein, 2003). They seek to connect with the public by offering these participatory activities, charged with the obligation to distil scientific material making it comprehensible and attractive, promoting effective participation between the visitor and the subject matter, over the common two to three hour visit time.

The subject matter of this project suited the remit of the modern science centre to enhance the 'public's engagement with science' in that it showed the direct link between scientific discovery and practical application of antimatter science in society. The human element of the science behind antimatter was exploited to show the relevance of science to society, and the content was designed to be appealing to both children and adults. Modern science centres now show an increased sensitivity to the social relevance of science, instead of the past practices of the transmission of scientific facts. They now attempt to show visitors how to think about and use scientific information to form well supported opinions, aiming to show visitors how scientific issues are important in the greater context of their society, their nation and the world. This signifies a shift in the communication focus of science centres to also address the social relevance of science (Lafrance, 2005; Nolin, Bragesj, & Kasperowski, 2003; Persson, 2000; White & Stein, 2003) placing an emphasis on exploring the skills people need to meet the challenges of modern life (Lafrance, 2005). Modern science centres are seen as places of education and entertainment for predominately younger children and their families through interactive and participatory experiences. They tend not to appeal to adolescents or childless adults. While there is no reason that the concepts presented in science centres should not appeal to people of all ages, often the idea of visiting the science centre is unappealing to these groups. Audience appeal was a key consideration of the project development, with aim on creating a product that appealed both to the typical science centre audience, and to the broader public.

The topical nature and complexity of this project's content lent itself to the creation of a temporary exhibit. Typically modern science centres commonly use topical phenomena for temporary exhibitions, and long standing scientific principles or concepts as the themes for more permanent displays (Desmond, 2004). Advanced or complex concepts do not easily lend themselves to permanent stand-alone exhibits, while temporary exhibits require less of a commitment of resources, and hence are able to be more adventurous in their design (Desmond, 2004; Falk, et al., 1992). These topics are better suited and are more frequently used in environments where an informed person can communicate and fully explain the science, such as public presentations, workshops and other opportunities for discourse, not through exhibits and their labels (Falk, et al., 1992; Yung, 2008). In some ways the topical subject matter of the project meant that it was well suited to a temporary exhibit; yet when considering just the complexity of the subject matter there is an apparent mismatch between the subject matter and the communication medium used.

Even though science centres are designed for participation, the stakeholder demands of this project led to the use of one-way communication models. The development of the exhibit's content and design was informed by a literature review on museum and science centre exhibit and label copy design and through informal interviews with local practicing industry professionals including; Questacon staff[1], Mr Simon Yates[2], Ms Iona Walsh[3], Mr Teon Harasymiv[4] and the Science Marketing and Development team from ANU[5]. The project was developed in line with industry best practice as appropriate, incorporating 'engaging' design features where relevant.

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[1] Primarily, interactions with Questacon were through Ms Wendy Yung, Education Officer, with further support from Dr Stuart Kohlhagen, Manager, Questacon Research and Development and Ms Sally D'Addio, Manager, Exhibition Services Operations.

[2] A Canberra based artist, who owns and runs his own graphic design company, Graphic Ark, Mr Yates also convenes a Masters course in Science Communication on design for web and print at The Australian National University.

[3] A Canberra based artist, who owns and operates the graphic design company Iona Walsh Art + Design.

[4] A Canberra based freelance photographer.

[5] Primarily, interactions with the ANU College of Medicine, Biology and Environment and the ANU College of Physical and Mathematical Sciences Marketing and Development team where with Ms Melissa Holland, Multimedia Coordinator and Mr Tim Wetherell, Chief Science Editor.

There is relatively little written from a PEST perspective on best practice for practical communication through one-way communication of complex scientific information in the science centre environment. To supplement this deficit in the literature a literature review was undertaken in the related areas of journalism, museum and exhibit design and public relations. In the following I document what I did as an Australian science communication practitioner using the literature available to frame the development of the project. The best practice recommendations and how they were used in this project are summarised under four themes. Supplementary information on the specific design decisions of the project and how they relate to each of the following themes is detailed in Appendix B.

Theme 1: exhibit design and visitor behaviour

Visitor experience is paramount to the success of an exhibit. In order to maximise the communication outcomes for the stakeholders it was essential to enhance the visitors' experience. Based on the industry recommendations the design of the project took into consideration the overall experience for the visitor, as generally museum visitors are after the overall experience, not to be educated on a particular topic (Cooper, 1993; Henriksen & Frøyland, 2000; Holbrook & Rannikmae, 2007).

Visitor conversations, irrespective if they are educational, social or both, increase the visitors' visit duration and enhance their experiences (Falk, et al., 1992; Hensel, 1987). The conversations that are generated from these shared experiences aid in cognitive development, and are also an important mechanism to stimulate, maintain, and extend interest in a subject (Western Australia Museum, 2006), by increasing both the quality and the flow of information (Hohenstein & Tran, 2007; Webb et al., 2003).

In order to maximise the communication objectives set by CAMS based on the five key messages, it was essential to maximise the visitors' conversations, which in turn can enhance their experience but can also increase their knowledge on the subject. The desire to generate conversations is arguably participatory motivation stemming from a one-way mechanism. To achieve these objectives the text on the panels used rhetorical questioning, iconic imagery, and exploited the human aspect of antimatter science in an effort to appeal to the audience.

Theme 2: language content and layout

Generating 'holding power' in an exhibit is an important facet of museum design. Individual exhibits have less than a second to make an impression; the right words and images working together can forge connections between the visitor and the exhibit (Blunden, 2004; Serrell, 1996). To capitalise on this phenomenon, attention grabbing design, catchy titles and striking and relevant imagery were used. Studies on visitor behaviour show that visitors spend more time looking at objects than reading labels (DeRoux, 1999), labels are seldom read in their entirety and over time visitors' concentration wanders and less attention is paid to the exhibits and their labels (Falk, et al., 1992).

The content and themes presented in the exhibit were chosen to be relevant to the individual to build personal connection to the visitor to maximise the probability of knowledge assimilation, longer visitor stay time and cognitive development, as the most successful exhibits are those that build a personal connection between the topic and the visitors' experiences (Ballantyne, Hughes, & Moscardo, 2008; Desmond, 2004; Falk, et al., 1992; Western Australia Museum, 2006; Yung, 2008). To maximise this, commonly known phenomena and comparisons were used including: spaceship propulsion and *Star Trek*, the scale of destruction caused by atomic bombs, the energy required to power a household light bulb, and by exploiting the human element in the telling of the stories of its discovery and through the section on medical applications. The written content was developed in consideration of the intended audience's ability, aimed primarily at a high school level, but with concepts and terminology that reached a year 12 reading level in an effort to appeal to and challenge all readers as per the stakeholders' requirements, despite industry recommendations of a sixth grade reading level for written content (Falk, et al., 1992; Serrell, 1996). In an effort to enhance the comprehension of the scientific terminology and jargon of the written content and to compensate for the likelihood of panels being read out of order, the text included consistent and general terminology linked to its scientific counterpart i.e. 'antimatter, positron,' (general, jargon).

Theme 3: imagery

Imagery was a key feature of the exhibit design. The imagery selection was particularly important for Questacon who saw the exhibit as being primarily a series of images with accompanying text. The text-based panels were enhanced through the use of illustrations and images by relating content to images making the panels more attractive, easier to read and more memorable than text only labels (Serrell, 1996; Yates, 2008; Yung, 2008). In the development of this exhibit key imagery was used to support the complexity of the content, as iconic images are particularly useful in describing objects, people or places mentioned in the text, representing abstract structures and showing spatial relationships. They can also be used as maps, to demonstrate instructions, to put unfamiliar objects in context, and to emphasise key points (Ballantyne, et al., 2008; Vieira, 2008). The use of iconic imagery, to capture the visitors' attention, can be seen in the examples of the use of the *Starship USS Enterprise* and Einstein's famous equation $E=mc^2$.

Due to the primary stakeholder's requirements, image selection was secondary to the written content, and needed to both adhere to industry standards for best practice and ensure cohesion between text and imagery. To ensure cohesion between content and imagery each image was captioned to enable the visitor to understand the topic of each panel as it relates to the image without having to read the panel in its entirety (Serrell, 1996; Yung, 2008).

Theme 4: physical design, positioning and the final product

The physical positioning of the final product was constrained by the location of the main visitor transit path at Questacon. The isolated and linear location worked in the project's favour. It avoided any discordant situations with the content in the existing exhibits. In addition, unidirectional spaces are ideal for sequential exhibitions such as this one, as they allow each panel to be viewed in order from point of entry. This enhances the visitors' experience as it enables comparisons and conclusions to be made about the topic without assistance (Cooper, 1993; Falk, et al., 1992; Mashantucket Pequot Museum and Research Center, n.d.; Yung, 2008; Yung & Kohlhagen, 2008).

In order to maximise the success of the project, additional communications and supplementary programs were used to raise the profile, draw attention to the exhibit, and expand the audience reach (Desmond, 2004). As part of the delivery of the project a series of public lectures based on the content of the exhibit were delivered by the Director of CAMS concurrent to the panels being on display at Questacon. Another mechanism commonly used is to have a prominent figure open the exhibition which will to attract an interested and influential following that may recommend the display to others (Desmond, 2004). For this reason, and to celebrate the project, the exhibit was formally opened by the CEO of the ARC, Professor Margaret Shiel, in February 2009, attended by senior representatives from the sponsor partners including the Director of CAMS, Acting Director of ANSTO, Director of Questacon, and representatives from the ANU including the Vice-Chancellor, Dean of Science and Director of CPAS. The final full 31 panel display 'Antimatter – does it matter?' was hung in mid January 2009 until 31 March 2009 and was seen by over 50,000 visitors.

Formal evaluation of any science communication activity is recommended by the literature as an ideal, however it was out of the project's scope in my role as the project manager, as the stakeholders showed no interest in resourcing a formal evaluation process. Anecdotal feedback on the panels by the Questacon staff suggested that they had received a number of positive comments by staff and visitors.

The client-adviser relationship is paramount to the success of the project. The stakeholders' objectives were in contradiction to the PEST literature recommendations for best practice of dialogue and participation. But the role of an adviser to is meet the client's wishes. In order to deliver on and satisfy their objectives, I was unable to adhere to the best practice recommendations for science communication as the project was forced to use one-way communication to meet their requirements.

Understanding the client-adviser relationship is important for a successful and productive working relationship. There is little written on client-adviser relationships from a PEST perspective, so in order to guide this project a literature review was undertaken in the broad area of client adviser relationships in the project management and finance fields. Further discussion on the best practice recommendations that guided the development of this project in terms of the client-adviser relationship, and specifically my role as the adviser, are detailed in Appendix C.

Project outcomes

This real world case study is evidence that one-way methods of communication are alive and well because they are often ideal in satisfying the stakeholders' requirements. More participatory methods of two-way communication were deemed insufficient to cope with the scientific complexities of the content, too expensive and not broad enough in audience reach, to address the breadth and depth required by the stakeholders for this project. In addition to the use of one-way communication this project highlights the prevalence of the deficit model view of the public, in that CAMS sought to remedy the public's deficiency by educating them about the science behind antimatter. This experience emphasises the disconnect between science communication theory as presented in the literature and the reality of undertaking a science communication activity on the behalf of multiple stakeholders. Despite not conforming to the norms of dialogue, participation and alike, it is of benefit to this discussion to make note of the engagement model employed by Kang (in Metcalfe et al., 2012), on provoking change within, as a useful description. Therefore defining exactly what we mean by 'engagement' will help practitioners set standards for evaluating success or failure, and will help science communicators figure out what we should be doing. If a 'scientifically engaged Australia' is likely to involve considerable one-way communication as this chapter suggests, then is that bad, and what is it we want exactly, and then through what mechanisms can these aims be achieved?

Chapter summary

This review highlights the discussion present in the formal literature on the persistence of the deficit model and one-way methods of communication, despite being theoretically superseded by other potentially more participatory approaches. As discussed earlier in this chapter, one-way remains a popular model of communication. Despite its default and simplistic nature there is evidence in support of its use in specific circumstances; crisis communication is a primary example of this. While the individual motivations for using one-way communication vary, ranging from it being less resource intensive, the default method, or even the ideal method when communicating a fixed message, the literature does support it as a legitimate and fit for purpose approach to communication. Inherent to all communication is desire to tell someone something they do not already know, this wish to communicate is often without context, independent of any consideration of the intended receivers' interests, pre-existing knowledge or ability to comprehend. This notion continually reasserts itself in the motivations behind many science communication agendas. The persistence of the deficit model in practice in the current era of science communication is well documented throughout the literature, yet most scholars do not themselves support it.

As an extension of this, the case studies presented here report on the use of one-way methods and in some instances the deficit model in real world communication activities. These case studies emphasise the disconnect between the theory and practice of science communication providing evidence as to the legitimate and continued use of one-way methods in current science communication practices. The reality of science communication in practice means that one-way methods remain a popular choice by communicators who need to serve the interests of their employers, clients or funding organisations. Despite this commercial reality, in some cases there remains a genuine use for one-way methods of communication in creating a 'scientifically engaged Australia'.

CHAPTER FOUR – SCIENCE COMMUNICATION-THEMED AUSTRALIAN GOVERNEMENT POLICY DOCUMENTS AND THE QUESTION OF A SCIENTIFICALLY ENGAGED AUSTRALIA

Government reviews and reports can lead to national reforms, having an impact on future policy directions and budget decisions. While not all government reports have a significant impact on the everyday lives of the public, some do have significant and lasting effects. Where this occurs, typically these reports have represented the broad view of the relevant stakeholders, as defined by the steering committee, through the consultation process. This can include national and international industry professionals, the public and public organisations, and critique of other local, national and international government reports.

In a practical sense, understanding government reports and policy directions is key to understanding the environment in which we operate, as policy reports can have an impact on funding priorities. The changing needs and priorities of the political or funding environment can have direct flow-on effects and are essential in informing strategic decision making and enhancing outcomes for any organisation operating within the political environment.

This chapter provides a third source of information about what a scientifically engaged Australia might look like. Through a critique of key government reports, it illustrates the current political environment with respect to science communication in Australia. The purpose of this chapter is to build a narrative of the evolution of science communication in Australia. This approach calls for the detailed critique and interrogation of the data in order to draw out the emergent themes. Through a process of constant comparison it enables the identification of the underpinning categories and intrinsic relationships between the reports (Hallberg, 2006; Howard-Payne, 2016; Jeon, 2004; Smith, 2015; Walsh et al., 2015). This chapter will identify emerging political agendas and discuss the current Australian science communication environment illustrated by these government reports.

The *Venturous Australia, building strength in innovation* report released in January 2008 was the result of the recent change of federal government and the realignment of government portfolios. This report reviewed the current national innovation system making a number of recommendations that led to the development of the Australian Government's innovation policy agenda to 2020, *Powering Ideas: An Innovation Agenda for the 21st Century* released in May 2009. To 'help realise the goals articulated in *Powering Ideas: An Innovation Agenda for the 21st Century*' (DIISR, 2010, p. xiii) the Commonwealth Government in 2010 launched its *Inspiring Australia* report (IA), described as 'a national strategy for engagement with the sciences'. This report was the first national government-level report specifically established to further the aims of science communication, with the goal to create 'a scientifically engaged Australia'. This report, along with other key government reports that informed its creation, are examined in this chapter to ascertain a government perspective on the thesis question, 'what would a scientifically engaged Australia look like?'. Until the IA report, many science communication scholars and practitioners considered a national science communication strategy in Australia long overdue. This strategy brings Australia into line with many European countries, the UK and the US who are leaders in the science communication environment.

The materials for this chapter are limited to a sample of 13 key reports that provide an indication of Australia's political and policy science communication agendas. The review examines the most recent state and national government reports from 2007-2013, sampling from the total of 16 reports about science in Australia, eight national- and eight state-authored. The report selection was based on elements of currency and relevance. Those chosen either directly informed the creation of IA or are subsequent reports building on IA. As such, the reports selected for review focus on the models and initiatives used in the communication of science, rather than education or Australia's science capacity and research agendas, which were the subjects of those not included.

The reports selected for review are:

- *Stepping Up to Meet National Needs: Review of Questacon — The National Science and Technology Centre*. Department of Innovation, Industry, Science and Research, 2008.
- Coordination Committee on Science and Technology, Science Education and Awareness Standing Group. *Audit of Science Education and Awareness Initiatives Delivered by CCST Member Organisations in 2006/07 Financial Year, Results and Recommendations*. Coordination Committee on Science and Technology, 2008.
- *Science Connections Program Evaluation Report*. Evaluation and Business Planning Section, Department of Innovation, Industry, Science and Research, 2009.
- *Quantum Market Research, Community Interest and Engagement with Science and Technology in Victoria Research Report*. Victorian Department of Innovation, Industry and Regional Development, June 2007.
- *Sweeney Research, Community Interest and Engagement with Science and Technology in Victoria 2011* Research Report. Melbourne: Victorian Department of Business and Innovation, February 2012.
- *Inspiring Australia, A national strategy for engagement with the sciences*. Department of Innovation, Industry, Science and Research, 2010.
- *Inspiring Australia Expert Working Group on Science and the Media: from ideas to action*, Department of Innovation, Industry, Science and Research, March 2011.

- *Inspiring Australia Expert Working Group on Developing an Evidence Base for Science Engagement in Australia Recommendations*, Department of Innovation, Industry, Science and Research, March 2011.
- *Inspiring Australia Expert Working Group on Science Engagement into and for Australia's Tropical Region, October 2012.*
- *Inspiring Australia Expert Working Group on Marine science: a story for Australia, November 2012*
- *Inspiring Australia Expert Working Group on Inspiration from the Deserts: Science Engagement in and About Australia's Desert Regions, January 2013*
- *Inspiring Australia Expert Working Group on Indigenous Engagement with Science: towards deeper understandings, August 2013.*
- *Science for Australia's Future: Inspiring Australia, A Review of Initiative 2013*

The IA program, described as 'a national strategy for engagement with the sciences', was the first national government-level program specifically established to further the aims of science communication. The shift in science communication policy towards public engagement presented in the IA strategy reflects the shift in science communication scholarship, particularly from the influential UK proponents (discussed in Chapter 2), IA generally conforms to the dominant language and ambitions of this time.

The following narrates the creation of the IA strategy through a review of those reports that directly influenced and informed its development. These reports are preceding reviews that focus on the methods and environment with respect to science communication in Australia: the 2008 review of Questacon *Stepping Up to Meeting National Needs* (DIISR, 2008); the 2008 *Audit of Science Education and Awareness Initiatives Delivered by CCST Member Organisations* (Coordination Committee on Science and Technology, 2008); and the *Science Connections Program Evaluation Report* (Evaluation and Business Planning Section, 2009). The review of IA itself then follows, as do reviews of those reports that have emerged after IA. Collectively this approach presents a snapshot of the current Australian science communication policy environment.

Background to the creation of the Inspiring Australia Strategy

Report 1: The 2008 Review of Questacon — The National Science and Technology Centre

The *Stepping Up to Meet National Needs: Review of Questacon — The National Science and Technology Centre* report was released by Senator the Hon Kim Carr, then Minister for

Innovation, Industry, Science and Research in July 2008. The release of the report coincided with Questacon's 20th anniversary as Australia's National Science and Technology Centre.

This review, like many others of its time, followed a change in national government and a subsequent reorganisation of ministerial portfolios. It provides a clear and proactive narrative of Questacon's concerns and the role the authors see Questacon fulfilling following this leadership change. The organisational environment in which Questacon found itself at the time provided an opportunity to reimagine and renew itself.

The review framed Questacon as 'stepping up to meet national needs', and is focussed on its role and core function over the last two decades, addressing the specific areas of funding, governance, its relationship with the government Department it operates in and comparisons with other national and international institutions of a similar nature. The report identified that the then current governance arrangements inhibited Questacon from maximising its prospects to deliver on its mission, that Questacon has operated 'without an explicit Government mandate...and its key activities have been largely internally generated' (p. 4), and that 'this lack of an explicit mandate has led to a lack of clarity about the relevance and priority of some activities, for example, outreach and teacher support' (p. 4).

The outcomes of the Questacon review in part informed the development of the IA strategy. In particular, it identified the need for national leadership in science communication, positioning Questacon as that leader. The report makes note of Questacon's institutional relationships, from its memorandums of understanding with Scitech, the Western Australian state science centre, to 'provide a framework for cooperation' (p. 29), to its role in the partnerships with government research institutions, such as the Commonwealth Scientific and Industrial Research Organisation (CSIRO), through the 'National Science Partnership...comprising representatives from CSIRO Education, CSIRO Science Education Centres and state/regional science centres...formed in 2005 to develop cooperative projects' (p. 30). Arguably Questacon, as the National Science and Technology Centre, is uniquely placed to lead the nation's science communication agendas. However, the review did not propose a vision of the future for science communication in Australia as there is nothing directly stated in the report that attempts to define or imagine a SEA. Science communication principles and practices are not the focus of the report, as terminology and science communication theory are not discussed.

As the report focussed on Questacon's governance and funding arrangements, it is neither a critical review detailing the proposed future strategic directions of Questacon, nor is it a strategic document outlining a future vision. This report reflects on Questacon's current governance arrangements and begins to map out a desirable future for its governance and funding. However, the report provided broad strategic direction in terms of its 11 recommendations, analogous to a strategic document. Recommendation 1 called for the Government to endorse a mandate for Questacon '[t]o inspire future scientists and the wider community and enhance awareness and understanding of the contribution of science to Australia's future' (p. 6), a change from its then mission of '[a] better future for all Australians through engagement with science and innovation' (p. 5). The revised mandate was designed to provide a solid foundation for its activities. The terminology used in the mandates changed from 'engagement' to 'understanding' and 'awareness', which is contra to the usual trends in this field over the past 20 years, as discussed in Chapter 2.

The science communication practices of the Centre received little attention, but the authors did make note of the role of new media as a key tool in expanding the reach of the Centre. New media is also an area identified in the IA strategy as an essential mechanism in achieving its aims. The report included a table (reproduced here as Figure 2) that provides a clear summary reporting on various metrics including key communication features, relative visitor numbers, funding sources of a variety of notable outreach activities undertaken by the Questacon. One key feature of this table is the identified rationales against each program. It is important to note that these rationales are tied specifically to their respective program, however, general key themes are present that form an early articulation of how a scientifically engaged Australia may be envisioned from the perspective of the government sector. Evidence of rationales being specifically tied to the activity can be seen in the Shell-Questacon Science Circus and NRMA RoadZone programs with the aims of training science communication graduates and raising awareness about road safety respectively. However, broadly the rationales are focussed primarily on reaching a school aged audience with the goals to encourage them to continue to study science and then go into science-based careers with a focus on the importance of mathematics. Within this, other priority audiences have been identified including regional, rural and Indigenous groups. It is evident that these key rationales or desired communication outcomes identified here have influenced and informed the development of the IA strategy.

The authors identified and discussed the primary communication partners of Questacon as being government funded organisations such as CSIRO and the ABC. Universities are not included in this list, and this is somewhat surprising as the largest single segment of the science sector is universities, which arguably have a key role to play in the communication of science as they are the primary promulgator of scientific knowledge, exemplified in Questacon's origins at a university. Nor is industry included as a primary communication partner, though the authors acknowledged the relationships that particular corporations such as Shell and NRMA had with the Centre. The public is not listed as a communication partner either, but rather identified as a 'communication recipient.' In reimaging the public in this way, the authors focussed on ‘engaging’ the public in critical issues in the expectation that the public will learn from the process. Questacon’s proposed 2008 model of communication represents a shift from the ‘fun-fun’ model of the past to a ‘fun-forum’ model of communication.

Program description	Rationale	Target audience	Funding situation and source
1. Shell Questacon Science Circus—portable science centre and Graduate Diploma in Science Communication with ANU.	Increase Questacon’s accessibility in regional/rural/remote areas. Train Science Communication graduates.	Primary and junior secondary students and their families. National, regional, rural and remote. No. visitors 06–07: 108,464	$1.3 million p.a. from Questacon, ANU, Shell, earned revenue. External funding until Dec. 2009.
2. Questacon Smart Moves (including Invention Convention)—demonstrate the latest in science, engineering and technology innovation and entrepreneurship.	Inspire young Australians to pursue careers in maths, science, engineering and technology. Encourage young entrepreneurs in science and technology.	National, regional and rural secondary students. No. visitors 06–07: 70,971	$1.8 million p.a. from Australian Government (BAA) Funding for program lapses in 2011.
3. Tenix Questacon Maths Squad—interactive school shows and workshops highlighting important role of maths in everyday life.	Encourage positive attitude to maths. Support maths teachers in context of declining numbers of trained maths teachers in schools.	National, regional and rural. Strong focus on areas of low socioeconomic status, and indigenous communities. No. visitors 06–07: 37,191	$420,000 p.a. from Tenix Funded to June 2008. Letter of offer received to extend program to June 2011.
4. Questacon Science Play—workshops, publications and on-line support to foster early childhood science learning and development.	Research indicates most cognitive development occurs early in life. Support for parents, carers and teachers in the development of appropriate educational activities and strategies.	Children 0–6 years and their teachers, parents and carers. National, regional and rural. No. visitors 06–07: 1,728, 07–08: 6,500	$450,000 p.a. from Australian Government Funded until June 2009. This project is integrated with Science Squad and NRMA RoadZone through shared overhead costs.
5. Questacon ScienceLines—presentations, workshops and websites designed in consultation with Indigenous communities.	Improving education outcomes for Indigenous Australians is a national priority.	Remote community Indigenous students and their teachers. No. visitors 06–07: 6,141	Funding has lapsed. Was previously funded through DEST appropriation of approx. $450,000 pa.
6. Questacon Science Squad—high quality, educational and entertaining science shows in schools and public venues.	Encourage students to consider careers and courses in science and technology related disciplines. Develop positive attitudes to science and technology.	Sydney students, teachers and general public. No. visitors 06–07: 32,378	$230,000 p.a. from Questacon and earned revenue. This project is integrated and interdependent with NRMA RoadZone and Science Play projects through shared overhead costs.
7. NRMA RoadZone—road safety exhibits and programs in local libraries and school shows.	Raise awareness of the role of science and technology in road safety.	9–14 year olds in NSW Programs are primarily in Sydney. Exhibits are for hire nationally. No. visitors 06–07: 69,267	$380,000 p.a. from NRMA. Funded until 2010. This project is integrated with Science Squad and Science Play through shared infrastructure and staff.
8. Q2U—outreach program in ACT and region.	To increase accessibility of Questacon to ACT Region schools.	Primary and secondary students, the general public, corporate groups, ACT region.	$45,000 from earned revenue and Questacon appropriation.

Figure 2. Table 3 detailing the outreach activities undertaken by Questacon (p. 28).

Unsurprisingly the target audience for Questacon is young Australians, followed by teachers and then families. One aim articulated in the report is to encourage more young Australians to continue to study science, producing skilled graduates to become future scientists, and thus underpinning and continuing to enhance the nation's strength in research and innovation (p. 32). Another focus of the Centre is to increase the public's understanding of the importance of science and technology in shaping Australia's future (p. 32). The authors identified Questacon's goals as having a national focus, and a leading role in showcasing cutting edge science and technology, and thereby ensuring a better future for all Australians. The discussion and outcomes of the Questacon report can be seen as an early articulation of what is to come later in the form of IA.

Report 2: The 2006 - 07 Audit of Coordination Committee on Science and Technology Members' Science Education and Awareness Initiatives

Established in August 2005, the objective of the Coordination Committee on Science and Technology (CCST) and its Science Education Awareness Standing Group (SEASG) was to facilitate information sharing and collaborative work regarding the delivery of science education and awareness initiatives by CCST members. The CCST SEASG comprised 38 representatives from several government organisations: the Australian Nuclear Science and Technology Organisation; the Bureau of Meteorology; the Bureau of Rural Sciences; Biotechnology Australia; CSIRO Education; the Defence Science and Technology Organisation; the Department of Agriculture, Fisheries and Forestry; the Department of Communication, Information Technology and the Arts; the Department of Education, Science and Training; Geosciences Australia; IP Australia; the National Health and Medical Research Council; the Australian Research Council; the National Measurement Institute; and Questacon – the National Science and Technology Centre. Their report on science communication activities by member organisations is another precursor to the IA strategy, and presents the results of an audit of science education and awareness initiatives delivered by the CCST member organisations in the 2006-07 financial year.

The purpose of the audit was to 'assist [CCST] members [to] identify current levels of activity delivered by the Australian Government, trends and issues, strategies to enhance effectiveness and opportunities for collaboration' (p. 3). This audit was a replication of the 2005-06 audit, which identified 146 initiatives, containing no less than 533 discrete components, delivered by 44 CCST member organisations. The audit used an online survey that captured data and information across the following fields: participant numbers; intended target audience; geographical location of audience; type of activity; number of components within each activity;

method of delivery; venue – external or in-house; frequency and longevity of activities; funding source and spend per activity; initiatives with communication partnerships; intended outcomes; if any evaluation occurred; and how the activities linked to the National Research Priorities.

The outcomes of the survey informed the development of three recommendations suggested in the 2006-07 audit, that for the first time proposed centralised coordinated metrics for evaluating science communication activity undertaken at a national level:

> **Recommendation 1:** That an audit of SEA activity amongst CCST members continue to be conducted annually.
> **Recommendation 2:** That initiatives, including identification of Key Performance Indicators, be developed and implemented to promote evaluation of SEA initiatives.
> **Recommendation 3:** That communication and information sharing between CCST agencies delivering SEA [science education and awareness] initiatives be further developed and expanded (p. 3).

These recommendations are the first examples of support to move towards a centralised, annual evaluation of science communication in Australia based on key performance metrics. Recommendation 3 identified and responded to a perceived disconnect in science communication activities that could be addressed by stronger national coordination and leadership. These recommendations, in particular the aspects of national coordination and leadership and longitudinal metric based evaluation of activities, are an early articulation of the emerging IA strategy. This report provided the first discussion into the development of performance metrics and longitudinal measures in science communication activity.

This audit created a snapshot of science communication activities by member organisations and gathered information to provide an overview of the main trends in terms of activity and audience focus. It identified 'similarities, differences and proportions in service provision across the Australian Government. It also provide[d] a baseline against which future activity may be compared' (p. 3). In doing so it identified a number of points about the status of science communication in Australia that help to create a picture of what policy-makers envision as the future of Australian science engagement. The audit identified that activities are commonly targeted to very wide audiences and that very few are evaluated (p. 4). In addition, it highlighted that a large proportion of respondents shared the goals of promoting science-based careers, with primary and secondary school students the primary target audience. Evidence of these sentiments is also reflected in the IA strategy. Other key goals included the desire for general enthusiasm for science and appreciation of research, common goals for any science communication endeavour. In terms of current behaviour by CCST member organisations, the results highlighted that secondary school students and teachers are a major target audience for research performing agencies (such as CSIRO), and one-off initiatives are almost twice as likely to be delivered by research funding agencies, than departments or research performing agencies who are more likely to undertake repeated initiatives. All member organisations were concerned about the cost-effectiveness of delivering science communication programs, and the relationship between evaluation and funding, unsurprisingly as 'the higher the budget of an initiative, the more likely the initiative was to be not only evaluated, but evaluated externally' (p. 25). The audit identified the top priority of science education and awareness initiatives as the professional development of teachers and parents. This implied a desire to target and influence a student audience. This outcome highlighted an important national view on science communication audience priorities, and one now reflected in the IA strategy.

The 2006-07 audit forms a national measure of science communication activity, and provides a basis for future audits of Australian science communication activities, a sentiment later reflected in the IA strategy. The authors draw general conclusions and comparisons to the 2005-06 data, as they make note of the reduction in activities for the general population and an increase in activities aimed at secondary teachers and their students (p. 4). The information presented in the report is not of fine enough resolution to enable further comparisons. A detailed comparison between years might have indicated a trajectory in which science communication in Australia is moving, however the authors only gave a broad not a detailed comparison of this kind.

This report is an internal contemplative government document focussed solely on practices of CCST member organisations, and as such, was never intended to address academic principles or practices of science communication. The emphasis of this report is on science education and awareness, not participatory methods of communication. Like the Questacon review this is in contrast to the usual trend in science communication of 'engagement' as discussed in Chapter 2.

Overall this audit provides a useful narrative of the (then) present status of CCST member organisations' contributions and science communication activities. It presented commentary, for the first time, on the need for national coordination of science communication, calling for the introduction of national, longitudinal and metric-based studies into science communication activities. This audit also identified secondary school students and encouraging them into science based careers as a key communication goal of the CCST member organisations. In summary, the report forms a key narrative of the policy-makers' views on science communication in Australia, in turn informing the development of the IA strategy.

Report 3: The 2009 Report Summary on the Evaluation of the Science Connections Program

The 2009 *Science Connections Program Evaluation* report by the Evaluation and Business Planning Section of the then Department of Innovation, Industry, Science and Research (DIISR) was not publically available as at June 2015. On approaching the government department for a copy of the report the publications coordinator advised that the report would not be publically available and provided a two page summary on the Evaluation of the Science Connections Programs (SCOPE). A brief narrative of this summary follows.

The report summary outlined the progression of SCOPE, a national program operating from within a government department. The evaluation of the SCOPE program was in turn the primary precursor of, and largely prompted, the development of the IA strategy.

Introduced in 2004, the SCOPE program received $23 million in funding over seven years for 'promoting awareness of the importance of science, engineering and innovation in Australia's economic and social development, as well as encouraging young Australians to pursue science-based careers' (p. 1) and to 'provide a suite of measures to achieve its overall objectives' (p. 1).

This internal review of the SCOPE program was assessed against the measures of 'Expenditure Review Principles': 'appropriateness, efficiency, effectiveness, integration, performance assessment and strategic policy alignment' (p. 1). In particular, the review focussed on the following issues directly relating to SCOPE:

- Whether there was still a need for government intervention in raising science awareness and developing and retaining skills in science;
- If the current program represents the best response to any need to promote the awareness and value of science and innovation;
- Assessing if the SCOPE suite of initiatives represent the best mix of interventions taking into account changing business, social and environmental conditions;
- How SCOPE's science promotion activities relate to other government initiatives (eg. Questacon, CSIRO, the ABC and state governments); and
- What future initiatives might be considered in order to meet the needs of target communities (pp. 1-2).

The outcomes of the review found that SCOPE has

> had a broad reach and has made some significant achievements...[and it] delivers important outcomes including the Prime Minister's Prize for Science, National Science Week, the ABC Science Project, the Science and Engineering Challenge and the Ultimo Science Festival (p. 2).

The review highlighted that the primary focus of SCOPE initiatives was encouraging young people to pursue science-based careers, similar to other reports of this nature and consistent with the IA strategy. As an outcome of the review the 'evaluation found the need to rebalance Australian Government activity to place more emphasis on supporting basic science awareness promotion' and that better science communication outcomes could be 'achieved through greater coordination of science awareness resources within the [DIISR] portfolio' (p. 2). These statements imply that there is a need for continued support of this type of program, and that future incarnations will have more definitive guidelines, key performance indicators, and greater national coordination.

SCOPE's focus on the 'public awareness of science', in line with other contemporary reports, suggests the language and objectives of the SCOPE program is in contrast to the usual trend in science communication. Again, like other reports of a similar age, the terminology used here is arguably a product of its time and precedes the prolific use of 'engagement' as a description of science communication.

A key outcome of the review was the statement on the future of science communication calling for the development of a 'national science communication strategy' (p. 2) and commentary on the government's ongoing role in support of this national strategy. The authors highlighted the need for continued national support for science communication, to include the development of a successor program following the cessation of funding for SCOPE. The authors stated that what is needed is greater coordination and stronger leadership from within the portfolio in coordinating science communication activities across the whole of government. To achieve this the authors recommended the introduction of a 'separate area within the portfolio to exercise strategic leadership, policy development and improved coordination of the many participants in science awareness' (p. 2).

The upshot of this review is that the authors identified that SCOPE had reached the end of its practical life. This narrative contextualises science communication in Australia, because a direct outcome of this report was the establishment of a steering committee to oversee the development of the national strategy to achieve a 'scientifically engaged Australia' – the IA report.

Two studies entitled *Community Interest and Engagement with Science and Technology in Victoria Report* - an original 2007 study (Quantum Market Research, 2007) and an updated 2011 study *Community Interest and Engagement with Science and Technology in Victoria Report* (Sweeny Research, 2011) – provided key data on the publics' interest in and attitudes towards science and technology, and informed the development of the IA strategy. These studies focus on the Victorian public, yet form a representative sample of the Australian public. The addition of the latter study creates a longitudinal data set, the first of its kind focussed specifically on the Australian publics' views towards science and technology.

Report 4: 2007 Survey of the Victorian Publics' Interest and Engagement with Science and Technology

Commissioned by the Victorian Department of Innovation, Industry, and Regional Development (DIIRD), the *Community Interest and Engagement with Science and Technology in Victoria Research* report by Quantum Market Research was released in June 2007. Following a $1.8 billion investment by the Victorian Government in science, technology and innovation over the previous eight years, this report sought to 'gain a greater understanding of community attitudes to science and technology, and the drivers and other factors that influence and inform attitudes' (Quantum Market Research, 2007, p. 2). The findings of this study were intended to 'inform the development of new approaches to engage the Victorian community with science and technology' (p. 2).

This report was used as part of the development of the IA strategy as it provided key information about the Victorian public's interest and attitudes towards science that could be extrapolated to the Australian public, in particular the identification of the 'segment profiles' (DIISR, 2010). By extrapolating the results for the Australian public, they provided context, background and baseline data on the current publics' opinions and attitudes towards science and technology, informing an understanding of the science communication environment within Australia.

The sample size of this study was designed to be demographically representative of the Australian population. The research design was informed by earlier similar studies from the UK, European Union and New Zealand. In the data analysis, the authors where applicable made comparisons to a 2005 MORI UK study (Ipsos MORI, 2005) and drew reference to any statistically relevant influences such as gender, age or location (p. 31).

The report presented a broad discussion of the results of the study. The authors stated that the study will inform new approaches to public engagement, enhance awareness and facilitate dialogue on emergent technologies, identify the public's media preferences, convert general interest into 'engagement', and ultimately improve the public's relationship with science. The authors touch on the issue of the public's ability to understand complex information and the need for relevant and efficient science communication in order to maximise its success. This discrete study presented a dataset, one that forms a basis of understanding of the Australian public that can be used to further the vision of what a SEA would look like.

The authors frame this study with the statement that the public's passion for science begins at an early age and that the public's interest in science and technology respectively are proportional to one another, where 'science' is defined as ideas and 'technology' as tangible things. The decision to separate the two terms 'science' and 'technology' – as often these terms are used synonymously yet are fundamentally different – is an important and beneficial design consideration allowing the 'unpicking' of interest in the practical applications of science, as in technology, from the fundamental practice of science. By separating these terms it allows for further identification of the public's subtle interests and attitudes and it acknowledges the process of technological development in that it stems from the fundamentals of science. The authors defined the term 'engagement' in this study as 'reading about or using science/technology' (p. 11) and included many activities from watching documentaries, to museum visits, to reading about science. The term is not defined as part of the research methodology, but rather as part of the survey questioning. The use of the term 'engagement' used throughout the study is reminiscent of modern science communication understandings, yet its definition is limited and vague. It is not reflective of what are considered current public engagement practices and 'participatory' approaches to communication as discussed in Chapter 2.

In line with the remit of the study and its report, the key outcome of this study as discussed by the authors is the identification of six population segment groups and their associated 11 key drivers. The population segmentation is based on interest levels and information seeking behaviours and is modelled on the earlier studies undertaken in the UK and New Zealand. The segments are founded on the following three questions:

> Q5a - Firstly, can you please tell me how interested you are in science?
> Q16 - Do you actively search for information about science and/or technology?
> Q20 - When you have looked for information about science and technology in the past, have you generally been able to find what you were looking for? (p. 67)

The questioning was specifically designed to unearth identifiable population segments. The identification of the segments and their similarities or commonalities allow for comparisons across the segments providing useful information on the public's interest, information seeking behaviour and understanding, enabling targeted communication to specific audiences based on the segment profiles. The report defined the following six population segments based on attitudes towards science:

> **Segment 1: 23% of the population**
> Segment 1 is defined as *interested in science but not active in searching for science information.*
> **Segment 2: 27% of the population**
> Segment 2 is defined as *interested in science, active in searching for science information and able to find information that they can easily understand.*
> **Segment 3: 16% of the population**
> Segment 3 is defined as *interested in science, active in searching for science information but either unable to find it or when they do find it have difficulty understanding it.*
> **Segment 4: 8% of the population**
> Segment 4 is defined as *neutral towards science and not actively searching for science information.*
> **Segment 5: 19% of the population**
> Segment 5 is defined as *disinterested in science and not actively searching for science information.*
> **Segment 6: 8% of the population**
> Segment 6 is defined as *neutral or disinterested towards science but active in searching for science information* (p. 68).

The authors stated that

> interestingly, there is little demographically that separates the six segments although some differences have been observed and outlined...there are only marginal differences in terms of gender, location, age, education and other core dimensions (p. 69).

Population segments are a useful way to separate and analyse the public's interest in and attitudes towards science. Segmentation of the population enables more focus than dealing with a homogenous public group. By segmenting the public it enables the identification of target audiences specifically focussed on interest and attitudes rather than demographic factors. The authors were unable to make the link between the population segments and how these directly relate to the study's measures of 'public engagement with science and technology'. A causal relationship is implied, with those segments identified as being 'interested' were assumed to be also 'engaged'. In discussing interest and the use of the population segments, the authors stated that

> [c]entral to engagement is the identification of topics of interest, the presentation of information in an interesting and approachable format and pitching it at a level and with a style that speaks to the audience in a meaningful way (p. 16).

The identification of a causal relationship between interest and engagement enables the targeted exploitation of particular population segments to enhance their relationship with science. It also aids in creating a greater understanding of what a SEA would look like and how it is to be achieved. The authors also imply, without stating explicitly, a priority for communication to those segments that are currently disinterested in science and technology. This priority area is also highlighted in the IA report.

In addition to the segment profiles, the authors identified eight key areas or topics of interest that are likely to have a significant public appeal, including areas that have 'relevance to issues that are personal...[and] relevance to issues of the time' (p. 10). This provides a useful snapshot of key areas of the Australian public's interest in science and technology, and included the areas of: health, water, environment, climate change, food, children (issues relating to conception, childbirth, childhood development and quality of life), daily life (normalising science in relation to), and technology (in particular stronger links between technology and the science that enabled it). The authors noted that these areas can be used as a guide for future science and technology communication activities. In addition to this, the authors touch on the importance of drafting the perfect message to the public and appealing to their interests, stating that all people are capable of increasing their 'engagement' and awareness of science. In this discussion they do not comment on how or through what mechanism messages should be delivered, noting that communication is through both direct and individual means and that knowledge and familiarity play a large role in 'acceptance' and 'engagement' by the public.

While the study had a narrow focus on understanding the public's interest and attitudes towards science and technology, it provided a useful starting point for science communication professionals to better understand and target science communication to the modern Australian public. It is essential to acknowledge the key role this study had in informing the development of the IA strategy, in particular in the identification of segment profiles and key areas of the public's interest (DIISR, 2010). This study provided a useful dataset through insight into understanding the Australian public's interests and attitudes towards science, contributing to the understanding of the aims of the IA strategy and what a SEA would look like.

Report 5: 2011 Survey of the Victorian Publics' Interest and Engagement with Science and Technology

Commissioned by the Victorian Department of Business and Innovation, the *Community Interest and Engagement with Science and Technology in Victoria 2011* research report by Sweeney Research was released in February 2012. This study built on the research findings of the baseline study conducted in the 2007 survey just discussed.

This expanded study sought not only to 'determine differences that have occurred in engagement with science since 2007', but also aimed to provide commentary on the publics' views, to help shape future directions of science and technology investment, focussing on the relationship between the public, science and political decision making (Sweeny Research, 2011, p. 11). The motivations behind this study are based on the authors' belief that 'the economic, environmental and social benefits of Victoria's investment in science can only be fully realised by a scientifically literate and engaged public' (p. 8). This study is both grounded in the modern science communication literature, informed by a literature review and expert advice (p.3), and links into the IA report.

The authors contextualise the study by reporting on

> a range of important events relating to science and technology [that] have been well publicised in the Victorian and Australian mass media. These have potentially influenced Victorians' attitudes to and engagement with science; this serves as a contextual backdrop for this study (p. 9).

In addition to numerous environmental and technological developments, from climate change and drought to social media and the Large Hadron Collider, the authors make note of the release of the IA strategy, stating that it 'aims to build a strong, open relationship between science and society, underpinned by effective communication of science and its uses' (p. 10).

The societal and behavioural changes that occurred between 2007 and 2011 caused variations that are reflected in both the questioning and the subsequent analysis and discussion in this updated study. The changes see the inclusion of greater considerations of the impact of mobile devices and smartphones, greater use of computers and the internet as part of leisure time, and the importance of social media and in particular Facebook. Another surprising difference is how the term 'engagement' is defined. Here 'engagement' was defined as 'reading about, learning about or using science/technology' as opposed to 'watching documentaries, museum visits, or reading about science'. The focus shifted from the passive act of attendance to the active and outcome driven mechanisms of learning or using science. While the use of the term 'engagement' is in part reminiscent of the previous 2007 report, it is not clearly defined and reflective of modern science communication practices, the underlying implication that science communication is 'learning' being reminiscent of the PUS era. This is further amplified by the authors' comment that 'it is important therefore that the public are able to understand the fundamentals of science' (p. 8). The authors do not explain why they chose to modify the definition of 'engagement' for the later study.

In addition to the primary aim of 'engagement', the authors identify the broad aims that increased 'engagement' will lead to, where the public will take ownership of problems and take opportunities to participate in debate. The view is that this in turn will increase the public's trust in scientists and acceptance of policies and decisions motivated by the belief that this will therefore improve the economy and national competitiveness, as a

> public that lacks trust and understanding in science will be unlikely to engage. …For a society to take ownership of the problems, and conversely take full advantage of the opportunities…it is vital that we are able to place trust in the findings of scientists (p. 8).

In addition to these outcomes of increased national economical, environmental and societal benefits, the authors identified outcomes for the public that include becoming active in seeking out science and technology information, and the creation of a public that 'values' science and thus has greater trust and engagement with science. These outcomes are in line with the two definitions of PE from Chapter 2; the PE as the active involvement in science and the public's valuing of science.

A further difference in this study appears in the discussion over the segment profiles established by the earlier study. The 2011 report does not maintain the driver analysis presented in its predecessor, but it does retain the associated questioning and segment profiles, providing continuity and enabling comparisons to be drawn in the data. The authors presented the updated population segments based on attitudes towards science (below, where the 2007 results are in bold parentheses). One key difference is that the authors of the 2007 report stated that there is little demographically that separates the six segments; however, in the 2011 report the authors provided additional analysis and insight by mapping and reporting on any relevant demographic trends as they relate to each segment (summarised in parenthesis and italics underneath each segment):

> **Segment 1: 19% of the population (23% in 2007)**
> Interested in science but not active in searching for science information.
> *(More likely to be mature couples or singles with no children at home, quite well educated, but tend to be from lower income households).*
> **Segment 2: 37% of the population (27%)**
> Interested in science, active in searching for science information and able to find information that they can easily understand.
> *(More likely to be under 45 and in households made up of young people - either couples without children or sharing, this segment is the most educated and has the highest incomes, 60% of the segment is male).*
> **Segment 3: 16% of the population (16%)**
> Interested in science, active in searching for science information but either unable to find it or when they do find it have difficulty understanding it.
> *(More likely to be under 24 or over 55 – with a nuclear family household structure with younger children, this segment is well educated).*
> **Segment 4: 9% of the population (8%)**
> Neutral towards science and not actively searching for science information.
> *(More likely to have an Australian upbringing and least likely to live in a regional or rural area, lower levels of formal education and most common post-secondary qualification is TAFE).*
> **Segment 5: 13% of the population (19%)**
> Disinterested in science and not actively searching for science information.

(More likely to be between the ages of 18-24, more likely to be in households with children over 13 and be single parents, they have a low level of education where year 10 is their highest level of qualification and are from lower income households, two-thirds of this segment are female).

Segment 6: 6% of the population (8%)

Neutral or disinterested towards science but active in searching for science information.

(More likely to be under 45 and in families with children, they are most likely to live in regional areas, they are most likely to use a computer daily and nearly half use a mobile phone to access the internet, nearly two-thirds of this segment are female)(pp. 64 – 70).

In addition to the segment profiles, the added detail available in this study enabled the identification of a number of emergent themes present in the results. The authors conjecture that since the 2007 study there was an increase in the 'thirst' for more scientific information (p. 37). Gender has the largest effect for feeling informed about science (p. 86). Males are significantly more likely to suggest that stimulating their brain or work is the reason for their interest, whereas females are significantly more likely to suggest their family or environmental issues (p. 27). Older males have more of an appetite for technology (p. 38) and generally it is younger females that are less likely to be interested in and have a positive attitude towards science and technology (p. 27). Those most uninterested in science are younger, live in a rural environment and have a lower level of education (p. 28), and older age groups are significantly more interested in science (p. 26). It is the individual's level of science education that has the strongest effect on interest, followed by whether they work in a related industry, then age group and gender (p. 86). There exists a direct relationship between interest in science and feeling informed about science (p. 33). In terms of public opinions, half of Victorians had the perception that the information about science presented in the media is true (p. 38). Men are less likely to trust the media than women. More Victorians felt that the rate of change in technology is too fast as opposed to the rate of change of science. The report expanded on this issue, as the authors suggested that the 'rate of progress in science is perhaps less visible, being buried in academic journals or housed in laboratories away from the eyes of the public' (p. 39). Changes in behaviour since the 2007 study show that people's active seeking of science and technology information rose from 50 per cent to 60 per cent by 2011. Men were more likely to seek information and the predominant method was through the internet (pp. 54-55). The role of word-of-mouth and of the Internet increased moderately since 2007 (p. 56); in 2011 45 per cent of Victorians accessed the Internet via a mobile device on a weekly basis or more often, with most of these doing so on a daily basis (p. 62). The report made note of additional research undertaken by Sweeney Research pertaining to the study when discussing technology and the rise of the smartphone, which was not part of the earlier iteration, as the authors remarked that 'the Internet is the number one thing that 16-30 year olds feel they could not live without' (p. 32).

Similar to the earlier study the authors implied, but did not explicitly state, that disengaged segments are a priority audience for science communication initiatives. The report does provide a strong basis for further development in this area as it highlighted a number of useful emergent themes, including the importance of mobile devices and the internet, and the impact of age, education, gender and geographical location on the public's interest and attitudes towards science and technology. The review coupled the socio-demographic factors into the population segment profiling identified the following trends of note; those who are considered 'least interested and not active in searching for information' are more likely to be female, younger, less educated, with a lower household income, single parents, living in households with children over 13. Those who are 'more interested' are more likely to be male, older, highly educated and to have a high household income. These emergent themes can be considered and applied to directly contribute to Australian science communication policy and practices and were of particular benefit for the development of the IA strategy. This report, and the availability of the raw data, provided a useful tool that can be generalised for the entire Australian population, producing the nation's first longitudinal study into the public's attitudes towards with science and technology. In doing so, it enables a greater understanding of what it means to create a SEA.

The Inspiring Australia strategy and its Expert Working Group reports

Through the critique of key government reports considered thus far, I have established a narrative of the Australian political environment with respect to science communication that led to and informed the development of the IA strategy. In the following section I present a critique of *Inspiring Australia* itself and the subsequent EWG reports; *Science and the Media* (DIISR, 2011b), *Developing an Evidence Base for Science Engagement* (DIISR, 2011a), *Science Engagement into and for Australia's Tropical Region* (DIISRTE, 2012b), *Marine science: a story for Australia (DIISRTE, 2012a), Inspiration from the Deserts: Science Engagement in and About Australia's Desert Regions* (DIISRTE, 2013), *Indigenous Engagement with Science: towards deeper understandings* (DIICCSRTE, 2013), and the 2013 review of the IA strategy *Inspiring Australia Program – Science for Australia's Future,* unpublished at time of writing (DIISR, 2014).

Report 6: Inspiring Australia - a National Strategy for Engagement with the Sciences

Inspiring Australia, A national strategy for engagement with the sciences from DIISR is the most comprehensive, overarching national report on science communication in Australia.

Senator the Hon Kim Carr, then Minister for Innovation, Industry, Science and Research, officially launched it on 6 February 2010, at the 2010 Australian Science Communicators National Conference. The report proposed a national strategic initiative in science communication to support the realisation of the goals in the 2009 Australian Government report *Powering Ideas: An Innovation Agenda for the 21st Century* (DIISRTE, 2009). Generated in response to the 2008 Cutler review, *Venturous Australia: Building Strength in Innovation* (Cutler, 2008), *Powering Ideas* articulates the Australian Government's policy framework to guide the development of Australia's innovation system over the next ten years with the goal that increased innovation will make Australia more productive, attracting new investment, jobs and industries.

For the first time in Australia, IA outlined a national approach for community engagement with the sciences with the belief that it would increase the return on investment in research institutions, infrastructure and programs into the future. It identified the aspiration of a 'society that is inspired by and values scientific endeavour, that attracts increasing national and international interest in its science, that critically engages with key scientific issues and that encourages young people to pursue scientific studies and careers' (p. xiii).

IA's Steering Committee comprised the Chief Scientist for Australia, the Chief Executive of CSIRO, the Director of Questacon, a senior representative of the ABC and a Deputy Secretary from DIISR as Chair. Broad consultation of over 230 people from across the country was undertaken with a range of science communicators, educators, journalists and scientists. In addition, individuals and organisations were invited to make written submissions, and further studies were commissioned from a youth perspective and in a regional centre.

The report is structured around five chapters that outline the challenges for future Australia. The authors identified 15 key principles and recommendations that address these challenges of building Australia's capacity through the telling of Australia's story by 'engaging' all Australians. The report also discusses how Australia should implement and achieve these goals.

A key motivation behind IA was the idea that 'sharing knowledge powers innovation' and that to 'fully realise the social, economic and environmental benefits of our significant investment in science and research, we must communicate and engage the wider community in science' (p. xiii). The development of IA was motivated by the need for a scientifically engaged Australia '[f]or Australia to progress' (p. ix). The IA strategy articulates how this will be achieved through the formation of a strong and open relationship between science and society, underpinned by effective communication.

IA sought to deliver a strategy that will 'help realise full social, economic, health and environmental benefits of scientific research and in return win ongoing public support' (p. xv). It is aimed at creating an environment where '[i]nstitutions and policymakers will need to appreciate the importance of public engagement activity, support increased training and recognition for science communication practitioners, and seek, acknowledge and respond to public perspectives on science' (p. xv). IA outlined the need to develop a national framework for public engagement from key existing national, state and community-based infrastructure, with the goal to achieve balance between existing science communication initiatives and new 'strategically targeted programs reaching out to those not engaged through traditional science communication channels' (p. xv). To do this IA considers a range of activities for communicating science, encompassing (in its words) telling Australia's story abroad, briefing politicians and policy makers, enhancing the role of the media and staging 'novel' events to 'stimulate interest and encourage dialogue' (p. vii).

The report is structured around five chapters. Chapter 1 outlines the challenge for Australia and the importance of public engagement with Australian science. The four key motivations identified in IA are

> to increase appreciation of science in Australian culture, facilitate informed citizen participation in decision making and science policy development, boost confidence in the Australian Government's research investment and ensure a continuing supply of well-qualified science graduates (p. 4).

Chapter 2 is focussed on 'telling Australia's story': generating pride among the Australian public about science by creating a positive 'science self- image' and an 'awareness of Australia's achievements in a global context' (p. 26).

Chapter 3 set out how to engage Australian communities via nationwide high-profile events. It identified four programs aimed at having an impact on every segment of the population to improving the 'public perceptions of science and also its value and relevance to the wellbeing of individuals, communities and the nation' (p. 29). The IA strategy identified those currently not interested in science as a priority, to make them aware of the importance of science to society, followed by those who are already interested 'to help them take the next step towards critical and intelligent engagement, not only in their own interest, but in the national interest' (p. 29). These programs are aimed at satisfying three of the four objectives of IA. The programs are: 'science and society', promoting dialogue and participation (p. 31); 'engaging Australian communities', targeting families through community initiatives such as National Science Week; 'building partnerships – using networks' which focuses on science organisations and their networks, 'encouraging them to work together to raise awareness of Australia's science capability in areas reflecting Australian Government priorities' (p. 33); and 'strengthening the media's role in communicating science', aimed at improving the quality of science-related media.

Chapter 4 discussed the implications of the Australian Government's *Powering Ideas: An Innovation Agenda for the 21st Century*, in 'building Australia's capacity' to increase the 'supply of talented and competent science, mathematics and engineering graduates, postgraduates and research technologists' (p. 39). This aim is driven by the need to meet the requirements of a scientifically skilled workforce into the future. IA proposed strategies focussed on informal youth-targeted programs, opportunities for school students to use existing research infrastructure and 'brokerage between the needs of the school sector and the ability of the research community to provide resources to support learning' (p. 42).

Chapter 5 considered how the report's proposed initiatives can be undertaken most effectively. The authors outlined the current ad hoc state of play with respect to science communication initiatives in Australia. In response to the current environment and proposed IA strategy they outlined a 'national framework-local action' approach aimed at enhancing and coordinating science communication initiatives across Australia underpinned by national leadership and agendas as outlined by the IA strategy.

Through these communication mechanisms, IA posits that 'it should move the uninterested to become interested, the interested to become engaged, and a greater proportion of Australia's young people to undertake challenging and fulfilling careers in the sciences' (p. 55).

IA has the goal of creating a 'scientifically engaged Australia', specifically:

> to develop the relationship between science and society, and thus enable the sciences to achieve greater value by creating 'a scientifically engaged Australia'. By this we mean a society that is inspired by and values scientific endeavour, that attracts increasing national and international interest in its science, that critically engages with key scientific issues and that encourages young people to pursue scientific studies and careers (p. 2).

As elsewhere, the term 'engagement' seems ambiguous here, being used both to frame all of these aims and also (somewhat tautologically) to define one of them ('a scientifically engaged Australia [is] a society that ... critically engages with key scientific issues' (p. 2)). The authors use broad descriptions when defining what is meant by 'science' or 'the sciences', including:

- the natural and physical sciences, such as biology, physics, chemistry and geology
- the applied sciences, such as engineering, medicine and technology
- newly emerging and interdisciplinary fields, such as environmental science, nanotechnology and phenomics

- mathematics, a field of study in its own right, as well as an essential tool of the sciences
- the social sciences and humanities, critical to the interface between science and society (p. ix).

These descriptions highlight the broad range of disciplines encompassed in their definition of 'science', extending to the humanities. Arguably the inclusion of the social sciences and humanities within the remit of 'sciences' could be considered out of place – a slight wording slip when the report was written. The intention seems to be to emphasise their important role in interfacing between science and society – such as through science communication. The authors do not explicitly identify any priority areas within this group, yet later in the report they touch on those areas which students should be encouraged to study further, broadly stating 'science, mathematics and engineering qualifications at university', implying a preference over, and separation from, the social sciences (p. 39). In a political or economic sense, prioritisation of areas or disciplines to communicate could highlight areas that Australia excels in, areas of recent government investment or paving the way for areas that may become significant to the future economy. The subsequent IA EWG reports can be considered to do just that.

In defining what is meant by science communication the authors discuss how

> [i]t is accepted that there are many different levels and kinds of science communication, with many organisations and individuals involved using many different media. The terms 'science communication' and 'communicating science' are used interchangeably; however, 'communicating science' is generally preferred, as it implies a more interactive process (p. x).

In clarifying the terminology here as 'communicating science', the authors imply communication motivations reminiscent of the PEST era. They proposed the development and delivery of programs 'based on best practice, informed by up-to-date audience research, and measured uniformly and consistently for outcomes and impact' (p. 55) while simultaneously looking towards the current providers for more of the same 'continuing successful programs' (p. 29). The authors identified that there are existing successful programs and seek to continue and refocus them in order to attract new audiences and greater involvement of organisations at national, state and local levels. Government reports do not commonly include formal scholarly evidence and referencing, and IA is no exception, but the discussion throughout includes elements reflective of current science communication principles, and the authors do propose the inclusion of new activities and less conventional approaches, such as dialogue events. In particular they propose a 'science and society' annual forum, where the science communication community, policy makers and the public are 'engaged and consulted' about science and technology issues, targeting new audiences among those who have been previously disengaged.

IA conflates the terms 'engagement', 'communicating science', 'science communication', and 'implied interactive processes', using them interchangeably particularly in relation to how the terms 'engage' and 'engagement' are used. These latter terms are sometimes used as active action of PE, for example: 'leading to greater engagement with the sciences and science-related issues. Such engagement will help solve the environmental, economic, social and humanitarian problems facing our country and the world' (p. 19). These terms are at times used as a description of the action of the communication of information, for example, '[s]till others may engage with science, but never describe themselves as doing so – for example, in seeking health information on the internet' (p. 26). In other places they are used as a synonym for the act of science communication, for example in the general aim to 'maximise the effectiveness of science engagement activities across the nation' (p. 15), and the need to establish 'nationwide science engagement activities' (p. 16). While this may appear a matter of semantics, it becomes an important issue when critically looking at what IA is trying to achieve, and how it sets out to accomplish this through 'engagement'. In these circumstances a clear definition of 'engagement', what it is meant to achieve, and specifically by what mechanisms, becomes a necessary precondition.

The authors outlined four key reasons why the Australian Government should invest in science communication, alongside investing in science:

- increasing appreciation of science in Australian culture,
- facilitating informed citizen participation in decision making and science policy development,
- boosting confidence in the Australian Government's research investment, and
- ensuring a continuing supply of well-qualified science graduates (p. 4).

These reasons form the basis for a SEA in the IA strategy. From these overarching motivations, and the four key outcomes of IA discussed earlier, the authors identified a number of measures of success based on each key outcome, as depicted in Table 1.

Some measures are more targeted than others. For example, consider an increase in international students versus the ability to know CSIRO is a leading research institution: the former is outwardly focussed in terms of Australia being the place of choice for study, whereas the latter is a reflection on the public profile and awareness CSIRO has raised within the Australian community. Not all measures of success are this easy to quantify; for example, measuring the content and frequency of 'people talk[ing] about the sciences in social settings' (outcome 3) may be problematic to measure (p. 21).

IA contains numerous aspirational or 'motherhood' statements. Motherhood statements are by design feel good platitudes, with which few people disagree. These statements can

Table 1

Measures of success that address the four key outcomes of IA

Four key outcomes of IA	**Measures of success**
Outcome 1: A society that values and is inspired by scientific endeavour	The ability for the public to be able to identify Australia's leading research scientists and agencies
Outcome 2: A society that attracts increasing national and international interest in its science	An increase in international sabbatical, PhD and Masters students and post doctoral researchers in Australian institutions
Outcome 3: A society that critically engages with key scientific issues	An increase in science media
Outcome 4: A society that encourages young people to pursue scientific studies and careers (pp. 3-4).	An increase in enrolment of local students in science, engineering and mathematics

give the appearance of strategy and vision but on closer inspection of surrounding text they may not be backed up with supporting evidence.

The use of aspirational statements in IA highlights that the authors know what they want to achieve but not necessarily how to get there. For example, the authors state that 'in effect, national leadership will enable the nation to work together so that the whole becomes "greater than the sum of its parts"'(p. 15), call for the 'promotion of our science and research achievements nationally and internationally' (p. 45), and remark that 'a scientifically engaged Australia...will increase the return on investment in research institutions, infrastructure, people and programs, now and into the future... communicating science and its benefits will promote such understanding and appreciation' (p. 1). While the research literature might contain evidence to back such statements, the report itself is written more aspirationally, resulting in assertions that appear to lack strategy and clear, targeted outcomes.

IA has the ability to be very influential as it establishes the vision for science communication in Australia. The later EWG reports address the practical details of the implementation of this strategy, one that sees 'Inspiring Australia is too important to leave to chance' (p. 55).

Informed by the 2007 *Community Interest and Engagement with Science and Technology in Victoria Research Report* by the Victorian Government, IA sought to further develop 'research studies to provide baseline and longitudinal attitudinal data' (p. 47). There are varying opinions about the merits of studying public attitudes and opinions. Studies of this type have both intrinsic strengths and limitations (House of Lords, 2000), they are often complex and contain numerous constructs that contribute towards the individual's attitudes (Osborne, Simon, & Collins, 2003). Baseline and longitudinal measures are attractive mechanisms in adding quantifiable measures of success in ascertaining the public's views contributing to achieving a SEA, and are a key recommendation of the IA report.

When defining the public's profile IA again builds on the 2007 *Community Interest and Engagement with Science and Technology Report*. The authors described the public in terms of age, relative interest in science, and employment (for the adult segment), generating the segment groups as presented in Figure 3.

<table>
<tr><th>Population Segment</th><th colspan="12">Segmentation based on interest in science, actively studying science (for formal school age segments) or employment in a science career (for adult segment)</th></tr>
<tr><td>School Age (Preschool and Primary)</td><td colspan="12">Before Subject Choice</td></tr>
<tr><td>School Age (Secondary)</td><td colspan="4">Uninterested</td><td colspan="4">Interested but not Studying Science</td><td colspan="4">Studying Science</td></tr>
<tr><td>School Age (Teritary)</td><td colspan="4">Uninterested</td><td colspan="4">Interested but not Studying Science</td><td colspan="4">Studying Science</td></tr>
<tr><td rowspan="2">Adult Public (General Population)</td><td colspan="3">Uninterested</td><td colspan="3">Interested but not in a Science Career</td><td colspan="3">Interested and Engaged in Science</td><td colspan="3">In a Science Career</td></tr>
<tr><td colspan="12">Politicians and their Advisors; Public Servants, CEOs in Business and Industry; Judges; Secondary School Teachers; Primary School Teachers; School Careers Counsellors</td></tr>
</table>

Figure 3. A synthesis of the population segments as discussed in the IA report is based on age, interest in science, actively studying science (for formal schooling segments) and employment (for the adult segment), segmented against the publics' level of formal schooling or post school in adulthood.

The IA report discussed the development of each audience group, stating:

> a person's interest can be influenced by motivation, mood or issue. There are times when individuals may want nothing more than information, and other times when they might want to engage more meaningfully…people can move in and out of the various attitudinal groups almost daily. What these studies usefully show, however, is that although people's attitudes to science can be segmented, their attitudes do not necessarily correspond to their behaviour or their understanding (p. 9).

This model provides insight into how the authors see the public and the relationship between interest in science and engagement with science. The authors identified 'interest' as the primary motivator for engagement with the sciences, over attitudes; the latter as stated by the authors do not necessary correspond to behaviour or understanding in the public. This model is limited in that it makes the assumption in drawing correlations between studying science or that having a science career equates to engagement. It assumes that those in a science career are automatically interested and engaged in science, but it is conceivable that a person can be engaged with science but not interested. Other limitations of this model relate to the key employment areas identified in the adult segment. The inclusion of the particular careers is not substantiated by the authors; it can be assumed that those listed represent the key stakeholder career groups relevant to the delivery of IA strategy as a target audience for greater interest and engagement, noting that the exclusion of scientists suggests that they are deemed to be already ‘engaged’.

Figure 1 (p. 10) of the report, shown here as Figure 4, depicts the audience segments in their developing levels of ‘interest’ and ‘engagement’ in science, as a complex diagram suggesting pathways along which segmented groups can be encouraged to increase their interest in and engagement with science. The authors of the IA report stated that this is a simplistic model, and that progression to scientific engagement is not linear. They argued that the model ‘provides helpful markers for communicating science to ensure greater equity in reaching under-served parts of the community’ (p. 10). This proposed model seeks to outline the direction of progression in achieving SEA across each segment profile. In its present state it is of limited practical utility. Communication activities would need to be mapped onto this framework in order to take it to the next stage of practical utility.

Figure 1 Developing levels of interest and engagement in science

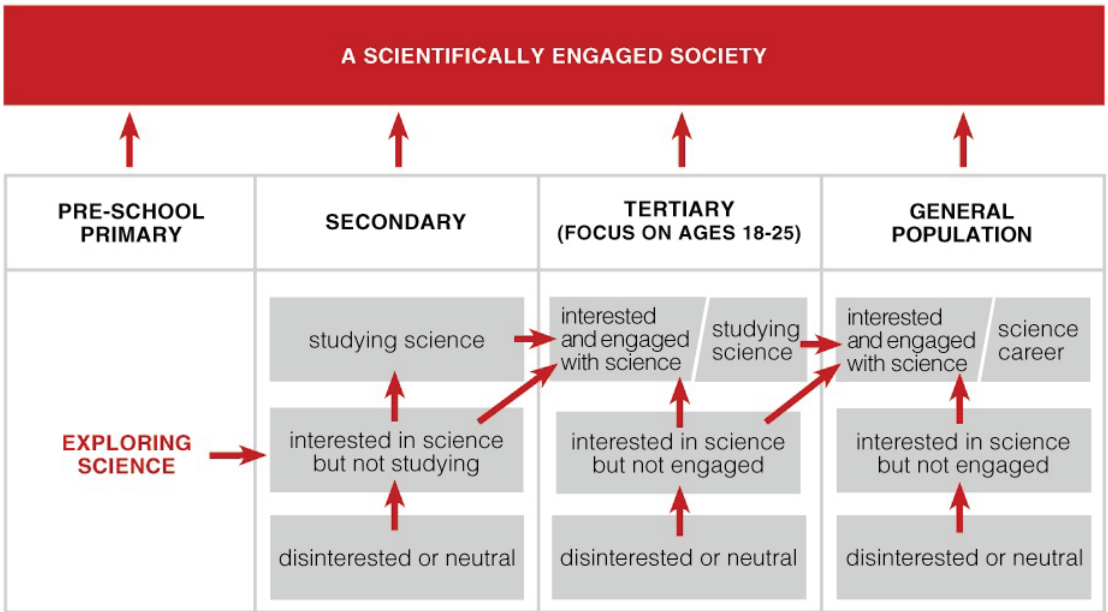

Figure 4. The relationship between the defined population segments and the proposed progression to achieving a ‘scientifically engaged Australia’ (DIISR, 2010, p. 10).

IA identified the mass media as a key communication mechanism to assist in achieving its goals. In particular, the authors stated that the ‘mass media are crucial in bringing science awareness to the wider public…they create perceptions—sometimes true, sometimes false—of what science is and what scientists do’ (p. 13). In particular IA detailed the use of mass media for the broader communication of Australian stories of scientific development and discovery through media ‘hooks’, and new media such as YouTube, blogs and social networking websites.

The report proposed that the Australian science community undertake both traditional and new media communication activities.

Recommendation 10 directly relates to the role of mass media in achieving the goals of IA. To strengthen the media's role in communicating science, the authors proposed that a 'national initiative [to] support science communication and media training for scientists [be established] and that a short-term working group be established to review mechanisms for further developing Australian science media content' (p. xix). The use of the mass media as an effective communication mechanism is further developed upon in a subsequent EWG report.

In Recommendation 13, the report proposed the creation of a 'national framework – local action' approach to science communication as a remedy to the (then) current largely uncoordinated and fragmented Australian science communication environment. This approach is designed to provide strong national leadership overseen by government, and to set up and facilitate short-term working groups, address priority issues, leverage additional support, identify and share 'best practice' and promote connectivity. The local action approach 'recognises the role of state and territory based organisations and funders and providers of science communication' (p. 47); support was envisaged to occur through national databases and a united web presence, and the review and implementation of effective science communication activities to guide future initiatives. The national framework was intended to facilitate enhanced measurement and reporting of science impact, commission research studies to provide baseline and longitudinal attitudinal data, and monitor the performance of the national strategy against its defined outcomes.

The authors of the IA report believed that this framework would enable a coordinated approach to effectively 'engage' with science and technology, to create 'lifelong engagement in science through the wide range of local science-related institutions' (p. 55). To achieve this, the authors proposed the creation of a National Advisory Group and short-term working groups to provide expert advice on specific initiatives and topics, with respect to the broad goals of the recommendations (p. 50).

The report's language is reflective of current science communication principles that advocate the use of two-way and participatory methods:

> This program [*Pride in Australian Achievement* as part of the implementation of the IA strategy] will offer a range of activities and events promoting dialogue and participation in areas of science most likely to be of interest to those who are not interested in science; and using methods and venues 'outside the norm' for science communication. They will include the following types of activities:…

- use of less conventional approaches — for example, café scientifique, science in the pub, moderated television and radio programs, online forums, social networks and Twitter — to carry on dialogues with the public, scientists and policy makers about science issues of interest to people's everyday life, such as water, food, health, climate change and energy (p. 31).

These proposed actions are reflective of current science communication rhetoric. The dominant communication mechanisms identified by the authors focus on two-way and participatory methods. These methods are a prominent feature throughout the IA report, as not only part of the 'national framework – local action' approach, but also in achieving the general aims of creating a SEA.

As a first attempt IA presents a science communication strategy that begins to articulate the aim of creating a SEA and what this means for the four outcomes and in turn 15 recommendations of the report, that if supported would evolve over time. This initial strategy is in line with the latest science communication methods. The language used in the IA report is dominated by the use of the term 'engagement' and with this it implies the dominance of two-way communication methods over one-way. However, within IA there is much mention of one-way communication methods. The authors make note of a preference for using the term 'engagement' over communication as communication is perceived as one-way, yet in their broad attempts to define the term 'engagement' it often resulted in it simply being used as a synonym for 'communication'.

The authors outlined a vision of science communication where these initiatives that are driven by the Australian Government's national objectives, described by a 'national framework – local action' approach to science communication, underpinned by Questacon, universities, policymakers and professional science communicators as the 'local action' component. IA had a particular focus on communication activities. It identified the need to share best practice and to develop an integrated and coordinated range of activities, pathways and communication priorities, that are further developed in the subsequent EWG reports. The authors identified the importance of relevance in enhancing 'engagement' with the public and the benefits of doing so in an 'informal setting' using both new and existing communication methods.

IA has a strong focus on school students as their primary audience and then teachers with the goal of encouraging students into science careers. This is followed by a strong focus on the broader community, with the priority audience being those individuals who are considered not already engaged. The authors do make note of the metro-centric nature of science communication and the need to consider the diversity of the public including Indigenous communities and those with English as a second language. IA notes that public actions as a result of ‘engagement’ include the increase of school students continuing science in university and going into science careers, and the public using science to inform their decisions and inform public debate.

The IA strategy aims to empower the public enabling them to fully participate in society through informed decision making and participation in policy development, with aims of increasing the return on, and safeguarding the future of, investment in science. In addition to these aims there is a raft of other desired goals from IA including but not limited to: societal, economical and environmental benefits; the desire for the public to have an increased appreciation, awareness and lifelong engagement in science; and a society that is favourable to technology development and emergent technologies. IA outlines the vision that through engagement with the public, societal and shared problems will be resolved, and that public engagement delivered as part of the IA strategy will compliment Australia’s Innovation Agenda, boosting confidence in Australian research with the aims to ‘engage’, ‘enthuse’ and ‘educate’ the public (p. 28).

In outlining the aims of IA the authors use is broad and aspirational statements to describe their strategy, but the strategy is limited. The goals – but also the mechanisms to achieve these goals – are very broad, with the authors seeking to ‘communicate all the things all the ways’.

Report 7: Inspiring Australia Expert Working Group on Science and the Media

The *Inspiring Australia Expert Working Group on Science and the Media: from ideas to action,* (DIISR, 2011b) expands on the recommendations of the IA strategy. Informed by a diverse group of experts from the fields of science communication, education, research, entertainment, and traditional news media, the authors

> review the state of science in the media in Australia and develop a set of recommendations that could help strengthen the media’s role in communicating science and ultimately increase public participation in and engagement with science (p. 4).

This review focussed on the media’s role in communications and in particular science communication, as

> the role of the media in informing the public and shaping public perceptions has been widely researched and the media are known to have great power in moulding public attitudes on a wide range of issues – science is no exception (p. 1).

Seventy-two one-on-one interviews with experts from across the field were undertaken to explore the role of science journalism in meeting 'the need for greater scientific engagement' (p. 1). The primary focus of this report is on traditional media and science journalism; the role of 'new media' is not addressed but the authors recommended that it would benefit from further exploration in a separate report.

The review identified a number of proposed future directions for science journalism initiatives to improve not only scientists' relationship with journalists, but to enhance science journalism as a whole, enabling journalists to operate more effectively and efficiently. In keeping with the views of the IA strategy, coordination, evaluation and benchmarking of activities were identified as an overarching goal. The review identified the need to bridge the 'divide between the entertainment and science communities' (p. 9). The authors put forward the idea of integrating scientific content as part of mainstream Australian media such as *Home and Away*, through the 'establishment of a Science and Entertainment Exchange and a Science-Media Innovation Fund to encourage the cross fertilisation of ideas between the scientific and entertainment communities' (p. 3). It is envisaged that this fund would provide 'incentives that encourage and enable producers, researchers and script writers to access science' (p.3). Examples of the integration of science in this manner can be seen in overseas television programming, in documentaries such as *MythBusters* and *How It's Made*, popular sitcoms and dramas like *The Big Bang Theory* and *CSI*, and even in reality shows, including shows with Australian franchises such as *Beauty and the Geek* and *The Biggest Loser*. The authors state that these initiatives can be used to communicate science for the 'public good' as part of raising 'awareness of science and provid[ing] a more 'human face' to expert opinion' (p. 9).

The authors recommended initiatives to enhance the relationship between science and the media such as media training of scientists and greater incentives for scientists to communicate. To achieve this the authors suggested that government research funding bodies 'should play a stronger role by introducing "carrots" in the funding process' (p. 12). The authors discussed the need for greater support for science journalists, including that 'developing better protocols to ensure fast accurate response during times of crisis would be beneficial to the media, the public and ultimately the government sector' (p. 34). The authors identified Government departments as having a role in supporting journalists through the presentation of statistical data 'in a way that enables the media and the public to access and use the data' (p. 34). They also stated that '[t]ools like mashups can enable much greater engagement between the public and institutions that create data' (p. 34). Mashups, being a combination, visualisation, and aggregation of data, have the aim of making existing data more useful for the consumer. Mashups illustrate the relationships within the data and present it in such a way that is visually appealing, assisting journalists in the communication of their message and the audience in aiding and enhancing their comprehension. For example the following Figure 5 illustrates a mashup that combines data from the Australian Bureau of Statistics, Australian Institute of Criminology, NSW Bureau of Crime Statistics and Research and Google Maps to compare and contrast Australian suburbs, depicting different aspects of each suburb, including socio-economic standing, education levels, and perceived safety levels (Metke & Henderson, 2009).

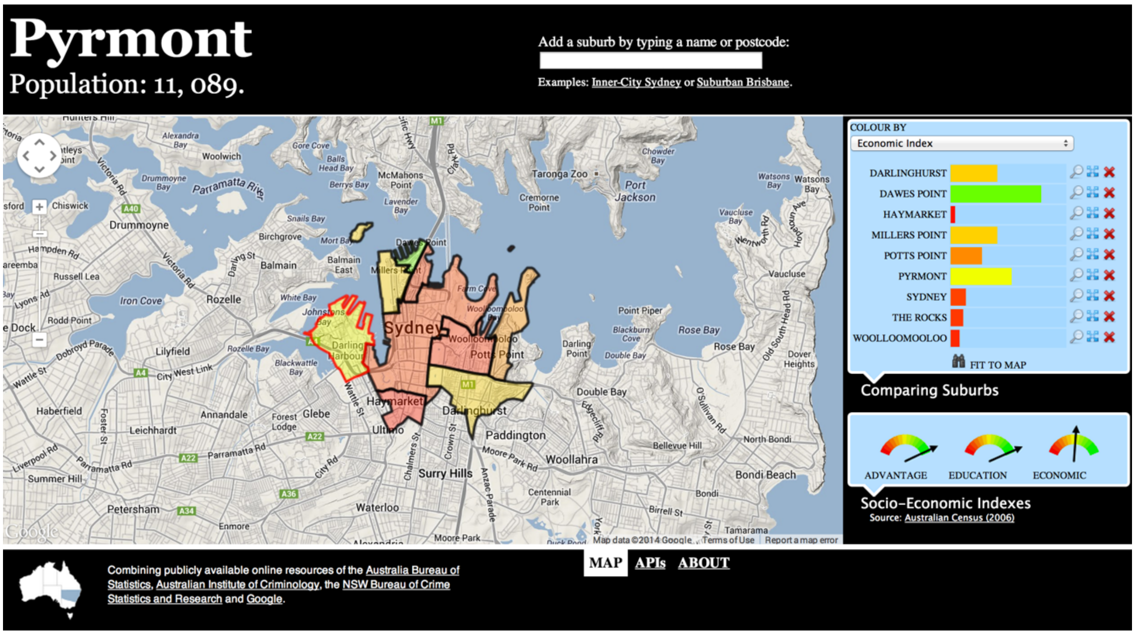

Figure 5. Mashup of Inner City Sydney suburbs comparing their socio-economic index represented by a colour from green (high socio-economic index) through to red (low socio-economic index). The indicators used are based on the socio-economic indexes of 'advantage', 'education' and 'economic' derived from 2006 Australian Census data. (Metke & Henderson, 2009).

The authors identified the desire for the public to have 'ownership' of science, and stated that to do this they need to have the ability to adequately interrogate scientific information, They argued that the

> need for greater scientific engagement and an ability to critically assess the credibility of scientific information couldn't be more compelling. The public needs to 'own' science and engage in debate about it—as much as people 'own' and engage with sport, music or politics. Science need not be seen as something 'out there' that the bulk of the population has no control over—society can and should have a say in the direction that research takes and therefore the type of society we build into the future (p. 1).

The desired outcomes the report emphasised include a strong focus on 'ownership' of science, for the public to engage in debate and critical thinking about science. The discussion is focussed on participatory methods that are inherently two-way or even multi-way, and in this it differs from the 'love of science' attitude of its parent report IA. Here the authors outlined a more radical vision of science communication in Australia, one that sees greater ownership and active participation by the public, reminiscent of key scholars like Wynne. The authors stated that ‘connecting science to what is being reported in the news engages students in an interactive way, allowing them to think critically about sources of science information and how the media reports on these issues’ (p. 39). The report did not distinguish who its target audience was, but in line with the goals of IA, implies that students are a focal point in connecting science in the news.

Unlike its parent report IA, the authors did not directly define the term ‘engagement’. Throughout the report the term ‘engagement’ is used often either in the phrase ‘public engagement’ or ‘science engagement’ merely as a description of a communication relationship or ‘use’. For example, ‘contributors to this report felt strongly that scientists need to embrace social media and that greater engagement with web tools such as blogs will benefit public understanding of science’ (p. 22). The aim of increasing public understanding is evidenced in this report, as the authors sought to use methods such as television, newspapers and web tools to convey information to the public. Motivations of increasing the public’s understanding are typically associated with early motivations of science communication of the PUS era as discussed in Chapters 1 and 3.

In keeping with the IA report, the ‘national framework – local action’ of IA is highlighted in the report with the view that incentives to communicate should be tied to research funding and that the cause would benefit from a champion. In this case they believed the Minister was the best champion. In discussing the national framework approach the authors did not propose a similar strategy for the future of science journalism in Australia. They identified the requirement for a ‘science-media coordinator’ as part of the implementation of the IA strategy to guide future activity with respect to the role of the media, and its relationship with science, in achieving the aims of a SEA. This report begins to outline the role of traditional media under the aims of the IA strategy, providing policy makers and science communication professionals with an understanding of the science journalism sector perspectives on Australian science communication through the media.

Report 8: Inspiring Australia Expert Working Group on Developing an Evidence Base for Science Engagement in Australia

The *Inspiring Australia Expert Working Group on Developing an Evidence Base for Science Engagement in Australia Recommendations* (DIISR, 2011a) also expands on the recommendations of IA. This EWG was commissioned to develop ‘a plan for identifying and sharing best practice for an evidence base for science engagement in Australia' (p. v). It seeks to address Recommendation 15 of the IA report that recognises the Nation's need for strategic design, delivery and evaluation of science 'engagement' activities, guided by:

> Recommendation 15: Developing an Evidence Base
> That the national initiative support a program of research in science engagement – such as baseline and longitudinal attitudinal and behavioural studies, activity audits, program evaluations and impact assessments – to inform future investment decisions by government and its partners (p. v).

The authors sought to frame the IA science communication agenda within the context of the Australian innovation system. They reference the *Powering Ideas: An Innovation Agenda for the 21st Century* (DIISRTE, 2009), which identified the pivotal role of innovation in the nation's future success by 'preparing Australia to face future economic, social, environmental and global challenges' (p. 11). This EWG report discusses the role of science communication in delivering on these goals, as the authors stated that the

> "constituent parts" of the national innovation system require the support of a sound science education, whose long-term goal is to strengthen the scientific literacy base of Australia, thus making the system itself stronger.
> Strengthening the "links between the parts" is, however, dependent on *science communication* between the parts. Each part of the system needs to communicate with and be understood by the other parts, if the system is to function effectively. Strong links are forged through the application of a deep understanding of the scientific relationships between the parts, and an understanding of the contributions each can make to the scientific enterprise and, by extension, to innovation. (pp. 7-8).

In developing this report the EWG undertook a review of national and international science communication literature, including government reports, to provide context and 'to develop best practice for an evidence base specific to the science engagement needs and requirements of Australia' (pp. 30–31). In addition, a series of consultations with 'two independent Expert Sub-Groups comprising university-based science communication researchers as well as developers and providers of science programs in Australia' was undertaken, and their feedback was used to inform the report's recommendations (p. 31).

To achieve its goals and to satisfy recommendation 15 of IA the authors identified three key themes and underlying actions of:

1. The Australian Public – calling for the development of suitable tools to measure public attitudes towards science and what the public requires for 'engagement';

2. Science Engagement Enterprises – outlining the need for the national evaluation of science engagement activities with respect to their goals and outcomes, and that the outcomes from these studies will be used to build activities on one another; and
3. Funding for Science Communication – highlighting the need for national recognition and formalised research funding to support science communication activities, including formal recognition by the ARC and NHMRC, and linking science communication activities to research grants.

In line with its parent report, the authors emphasised the important role of the humanities and social sciences as being integral to addressing 'complex societal relationships within which science has an important role' (p. 2). The authors raised the issue of funding arrangements, and the desire for national recognition for science communication research through formalised research funding, with a focus on increased government support to improve not only science communication scholarship but also to increase its practice, also key features of the IA report. The authors stated that 'funding of science communication research should not be restricted to traditional academic investigations, but should include the many aspects of science engagement enterprises that communicate science to the public' (p. 14). They argued that science communication should be funded in the same manner as science research – through government grants – as currently there is 'insufficient recognition nationally for science communication [and] this has an adverse impact on science communication research, which is essential to develop and evaluate effective innovative science engagement enterprises' (p. 13). The authors identified the disparity and confusion between the scholarship and the practice of science communication, as the argument of 'whether science communication constitutes its own field of research' (p. 13) is discussed at length. What the authors sought to achieve was for science communication to be recognised as part of the national competitive grants process and in addition that this process should not only support research into science communication but also the practical application of science communication initiatives.

Furthermore, the authors sought to enhance science communication by scientists themselves. Here the authors proposed the formalisation of science communication initiatives as part of the Australian competitive grant process; Recommendation 9 sought an outcome that will 'recognise and require, from the proposal stage of ARC and NHMRC grant applications, the communication of scientific research to a wide spectrum of constituents, within a framework of human endeavour (p. vii)'. The formalisation of these initiatives for all competitive grants assists in raising awareness within the scientific community of the importance of scientists communicating their research back to the public (DIISR, 2011a). Examples of this can already be seen in relation to the KPIs on outreach associated with ARC Centres of Excellence

(Australian Research Council, 2009), highlighting that funding organisations already acknowledge the importance of communicating with the public.

The 'national framework – local action' approach from IA is evident in this report, as the authors identified 'science engagement enterprises' as the 'local action' component responsible for undertaking the communication initiatives. As part of this the authors identified an exhaustive list of 'science engagement enterprises' including: government organisations such as CSIRO, ABC, Questacon and the Office of the Chief Scientist; science centres and museums; universities; academies; research agencies; professional and business bodies; and community-based organisations (p. 12).

As with the EWG report on the media, there is no specific definition for the term 'engagement' here, and again the term 'science engagement' is predominately used as a description of the communication relationship. The language used throughout the report includes those communication methods that are typically associated with one-way models of communication, diffusion and dissemination. For example, the authors stated that it 'is therefore clear that understanding and measuring engagement, diffusion and attitudes will inform immediate actions for effective dissemination across the economy' (p. 1). The persistence of these models suggests that they maintain some practical utility in delivering on the aims of a SEA. The authors do acknowledge that further work needs to occur to enable an accurate measure of the public, as the 'conventional measurements of scientific literacy do not enable more immediate innovation outcomes because they do not measure the nature and strength of the links between the constituent parts' (p. 1).

In the discussion on engagement, the authors emphasised the diversity of the nation and the 'importance of putting science communication research into a social and cultural context, particularly in a country with diverse and multicultural people' (p. 2). This view is motivated by pragmatic reasons due to the effect that disparate groups and their differing opinions can have on whole of nation initiatives. The authors outlined the need to understand the views of the diverse population in order to 'strengthen Australia's evidence base for science engagement, we need to investigate all contributing factors that will enable stronger links between the constituent parts of Australia's innovation system' (p. 2). The focus on the diversity of the population as a key communication area is in contrast to IA, which identifies the youth as the primary priority communication group, with a secondary focus on Indigenous groups and those for whom English is a second language. This EWG report provides no other commentary on proposed target or priority audiences.

The authors placed a strong focus on the role of new media, discussing communication tools such as blogs as potential avenues to facilitate broader PE. They outlined the requirement for these models to deliver 'definite and practical outcomes…[that] can effectively engage the Australian public' (p. 15). New media appears to be priority communication area identified in both EWG reports and would benefit from further exploration.

Overall the report is strongly linked to its parent report IA, guided under its national strategy and aim to create a SEA; it shares common language and repetition of themes and actions of the original report. This report provides a narrative that begins to build on and support the goals of IA with a focus on the aim of developing 'best practice for an evidence base specific to the engagement needs and requirements of Australia' (p. 31). Overall, this report begins to extend the strategy outlined in IA, operating under its aims to achieve a SEA with respect to developing an evidence base for science engagement.

Report 9: Inspiring Australia Expert Working Group on Science Engagement into and for Australia's Tropical Region

Inspiring Australia Expert Working Group on Science Engagement into and for Australia's Tropical Region (DIISRTE, 2012b). This EWG report was focussed on 'science engagement into and for the tropical region of Australia…a significant section of Australia's remote landscape' (p. 1). The EWG report stated that it will deliver initiatives that will assist in rectifying the disadvantage that tropic Australia has in the

> quality and impact of science engagement, weakening its ability to make genuine economic, social and environmental progress as the same rate as other parts of the nation…[that] directly impacts on the daily lives of all tropical Australians (p. 33).

This report builds on the recommendations of the IA report, in particular recommendation 8 – engaging Australian communities, recommendation 9 – building partnerships – using networks, and recommendation 12 – unlocking Australia's full potential. The authors outline a strategy that addresses the distinctly different challenges for tropical Australia including: its vulnerability to climate change; the nation's dependency on tropical Australia for the economy – resources, energy, agriculture, tourism; and urban development. The authors discussed how tropical Australia differs to southern Australia, commenting on the disproportionate activity in that the majority of science resources and effort is focussed in southern Australia, so that 'southern science concepts tend to drive northern agendas, at times leading to perverse outcomes' (p. 3). Features emphasised by the authors is that tropical Australia is an Indigenous domain in that the Traditional Owners have control of, and/or interest in, the landscape. In addition to this the importance of local knowledge was identified as being essential to this relationship and the 'most significant engagement issues for the Tropical EWG' (p. 17). Another area the authors focussed extensively on was scientific literacy, as tropical Australians generally have a lower level of scientific literacy than southern Australians, and have poorer access to the 'digital economy'. This in turn effects their ability for 'robust participatory democracy' (p. 4).

Like its parent report the language is reflective of the current science communication practices, as it described a 'shift in the language from science communication to science engagement' (p.5), and the desire to shift 'from a centralised information dissemination model to a participatory science engagement approach' (p. 4). However, the authors did not define the term engagement throughout the report, typically using it as a catch-all description for science communication, with a particular focus on enhancing the public's scientific literacy, for example the authors stated 'these strategies relate to the scientific literacy of tropical Australians, the collaborative institutional frameworks for effective science engagement' (p. vii). The authors discussed the need to establish a 'basis for sound community wide messaging on key scientific issues of importance to Australia's tropics' (p. 30), and identified the mass media as being essential to achieving their communication aims.

Paralleling IA, the authors identified students as a key communication audience, with the particular aim of encouraging them into 'careers in science and science teaching' (p.32). The authors called for increased investment by governments and changes to research funding systems to redirect resources into the tropical Australia initiatives. The notion of involving research funding agencies with the desire to have science communication initiatives recognised as part of the funding system parallels the view of the original IA report. As part of this discussion on the funding systems the authors recommended the establishment of a multi-disciplinary Journal of Tropical Australia with the objective that this will enable an integrated science framework across tropical Australia. As part of the implementation of these recommendations the authors identified the need for additional investment and policy change to aid in reaching these outcomes (p. 32).

Differing from the IA report the authors called for the decentralisation of government programs, stating that 'a more devolved approach to government decision making based on targeted investment in long-term strategic plans could build a more stable investment foundations for building scientific literacy' (p. 9). The authors add to this discussion stating how '[s]takeholders in the tropics, and often the science community itself, demonstrably favour more devolved, strategic and collaborative frameworks for science management at scales that make sense to them' (p. 14) including bespoke regional initiatives, in contradiction to the 'national coordination – local action' framework established in the IA strategy.

The authors identified 'seven broad, context-driven…themes of science engagement that need to be addressed for tropical Australia' (p. vii).

1. Building science literacy for all tropical Australians
2. Shifting science engagement cultures at the project and publication level
3. Building durable and trusted regional science brokerage and partnership arrangements
4. Forging effective science engagement in the Indigenous domain
5. Building science partnerships at industry/sectoral level to turbo-charge innovation
6. Ensuring science messages from the tropics engage southern Australia
7. Engaging tropical Australia in national science messages (p. vii).

These themes establish the context of what the authors identified as the topical areas with respect to science engagement issues and solutions in the tropics. From this, 20 recommendations were developed to deliver these themes, and from this emerged three primary strategies that underpin the recommendations and themes:

1. a pan-tropical narrative and alliance for science engagement
2. strong engagement frameworks in the tropics
3. community-wide foundations in science literacy (p. x).

The authors identified that these strategies are in 'need of more substantive scoping, analysis and refinement in the future' (p. x).

Overall this report is very broad, detailing numerous desired communication themes and directions over short to medium term time frames, with an equally broad remit of desired outcomes. The EWG report describes an aspirational and overarching vision for science communication in and about tropical Australia. The authors identified the high-level science messaging that relates to tropical Australia of 'climate change, food and water security, energy and the health agenda' (p. 26), however fail to identify any priorities or specific areas for future action. The exception to this was the report's strong focus on increasing the scientific literacy of those in tropic Australia, a motivation of the PUS era of communication. This report begins to outline the areas of importance in tropical Australia, however does not translate this into assisting to realise the goal of creating a SEA.

Report 10: Inspiring Australia Expert Working Group on Marine science: a story for Australia

Inspiring Australia Expert Working Group on Marine science: a story for Australia (DIISRTE, 2012a) expands on the recommendations of IA with a

> snapshot of [the] current approach to marine science communication in Australia, identifies some of the key issues and areas of opportunity, and makes a series of recommendations to help people involved in the marine sciences to build greater community awareness of the important role their work plays in our marine future' (p. 1).

The authors described that as an island nation 'Australian society has a deep cultural, economic, even spiritual connections with the oceans that surround us' (p. vii). The authors expanded on this as they outlined the unique set of benefits that the marine environment brings to the nation in delivering ecosystem benefits – particularly through climate regulation, the provision of food and energy, its role in imports and exports, support for national security, and in the opportunities it provides for recreation, sport and the arts.

In addition to the benefits the marine environment brings to the nation, Australians have a responsibility in relation to the marine environments under the United Nations Convention on the Law of the Sea which conferred on Australia the 'obligation to protect and preserve the marine environment while ensuring that marine resources are sustainably developed' (p. vii). In addition to environmental obligations and social responsibilities there is an undercurrent of economic motivation throughout the report, as the authors discuss that the '[m]arine industries employ thousands of Australian and contribute more than $40 billion annually to the national economy' (p. vii), going on to add that 'Australia's maritime limits also need protection against the unregulated movement of people, illegal fishing, and the introduction of marine pests' (p. 12).

This EWG built on the recommendations of the IA report, in particular: recommendation 4 – coherent action; recommendation 8 – engaging Australian communities; recommendation 9 – building partnerships – using networks; recommendation 12 – unlocking Australia's full potential; and recommendation 13 – national framework – local action (p. 4). It detailed

> four elements of a proposed national marine research and innovation framework.
> The three core elements – exploration, discovery and sustainability; observations, modelling and predictions; and marine industries development – are interlinked and highly complementary. The fourth element – engagement and knowledge transfer – underpins the entire framework to support effective engagement, close collaboration and technology transfer to ensure maximum effectiveness of the programs (p. 2).

The report delivered a ‘series of [26] recommendations for the science community aimed at increasing awareness of the importance of our marine domain and building support for increased investment in marine science, technology and innovation in Australia’ (p. viii). As part of this is authors identified six key themes to guide future marine science communication activities. These key themes are in line with the IA strategy, in particular the focus on the need for national coordination of activities, the role of the media in achieving the communication aims, the greater involvement of marine science to inform policy development, and the desire to ‘showcase’ marine scientific research to the nation. As part of this coordination and collaboration the authors discussed how existing organisations were able to expand the reach of the marine communication activities, namely museums, art galleries, science centres (p. 31).

Under these key themes the authors developed nine key communication messages to guide future activities, noting the particular desire to build on existing excellent activities and to ‘facilitate coordination and collaboration to achieve the full potential of current and future efforts’ (p. viii) and to ‘avoid fragmentation and duplication of effort’ (p. 15). This desire for collective action parallels that of the IA report with a quarter of the recommendations focussed on developing a national approach to marine science communication, and a third of the recommendations relating to ‘bringing marine science to the community’ (p. x) with a particular focus on formal education in achieving this.

The authors outlined a view that ‘raising community awareness and understanding of the function and value of Australia’s marine estate is the essential first step’ (p. 4). They went on to discuss how ‘teachers and marine education centre staff play an essential role’ (p. 9) along with journalists and researchers themselves. The role of formal education featured heavily throughout this report, the authors discussed the need for ‘consistent messaging across the marine science education community’ (p. 43), for research agencies to create marine science curricula, and that professional development of teachers would improve teaching of marine science.

There remains a strong focus on the public’s knowledge as the authors state that ‘effective public debate about current marine issues can only happen if there is broad access to appropriate information’ (p. 24). In line with the IA report the authors sought greater ‘engagement’ with marine science, yet what is encompassed under ‘engagement’ is not defined. The authors did discuss how ‘Australia needs stronger science awareness and science participation’ (p. 14), yet their comments do imply a sort of deficit model approach to communication, one where the public are only invited to participate in governance once they are informed.

The communication mechanisms that are identified within this report are largely (although not entirely) one-way and include 'publications, events and education programs, various forms of media activities (e.g. broadcast, print and web – including social media), lectures, local, national and international awareness activities…and support for community interest groups, amongst others' (p. 8). Not all mechanisms are considered one-way as the authors comment that citizen science is as 'an effective two-way mechanism for building connections between science and the public' (p. 24), yet there is an emphasis on mechanisms that change or influence the public's behaviour, understanding or awareness, not that of the communicator whether it be a scientist or an institution.

Similarly to the IA report the role of the media and new media were identified as essential mechanisms in delivering on the key communication themes with the view that new media are 'an increasingly popular tool as they offer a greater control over content and treatment of stories than is possible with traditional media approaches' (p. 42).

In line with the IA strategy this EWG identified '[t]he 'community' or 'general public' is seen as a high priority audience for many of the communicators' (p. 20). The authors discuss the particular communities relating to the marine environment, stating:

> [r]esidents of coastal communities often see themselves as being responsible for stewardship of the marine environments within their local area and Indigenous communities have a strong cultural and spiritual ties to their sea country (p. 23).

The role of Indigenous communities was briefly discussed, with the authors noting that 'social and cultural aspects of the marine environment are also critical, as shown by the long-term interests of Indigenous and non-Indigenous people in Australia's coasts and coastal waters' (p. 6). In involving the Indigenous communities the authors discussed the need to acknowledge the value of Indigenous knowledge, outlining a desire for genuine dialogue with these communities to promote trust and 'minimise the potential for community members to feel marginalised' (p. 38). This highlights pragmatic motivations in involving Indigenous communities, rather than two-way knowledge sharing as identified in the EWG *Inspiration from the Deserts* (discussed below).

The authors discussed the importance of evidence based decision making by governments, and they identified the need to 'build effective relationships with policy advisers and decision support teams' (p. 42) to enable this. They also identified the need for industries to have a greater number and improved 'interactions between marine science and marine-based industries' (p. 47). This report highlighted the importance of the marine environment to the nation, how it relates to key sectors of education, research agencies, community organisations, governments and industry. The report began to outline a communication strategy for marine environment guided by the original IA strategy, with a particular focus on the need for national strategy and collaboration, the importance of education, and the role of the media in achieving the communication aims. An underlying motivation of this report is the focus of the marine environment to the nation's economy, in particular in the areas of fisheries, energy, tourism and in ports and shipping. The inclusion of communication priorities as part of the implementation of this strategy would have been a significant advantage assisting in its implementation but also to enhance the understanding of what a SEA with respect to the marine environments would look like.

Report 11: Inspiring Australia Expert Working Group on Inspiration from the Deserts: Science Engagement in and About Australia's Desert Regions

Inspiring Australia Expert Working Group on Inspiration from the Deserts: Science Engagement in and About Australia's Desert Regions (DIISRTE, 2013) is focussed on the importance of deserts in Australia, stating that

> Australia is unique in the way that much of our national identity is based on romantic notions of the vast outback and the demands of a harsh and remote environment, while the political and economic powers of the country are located on the coast (p. 2)

Deserts comprise over 70 per cent of the country, generating '$90 billion in annual export incomes – more per capita than any other region of the continent' (p. 5). The authors sought to dispel the romantic notions of Australian deserts by reframing why a strategy for desert communication is important. Not only is it the most productive region in export income per capita in Australia, the opportunities within this region are 'essential to creating both inspiration and driving prosperity' (p. vii). The desert communities are also important to achieving the goals of a SEA as they are 'predominantly populated by Aboriginal Australians, who experience significantly poorer health outcomes and higher rates of chronic illness...than the non-Aboriginal or Torres Strait Islander population' (p. 5).

This report builds on the recommendations of the IA report, in particular recommendation 8 – engaging Australian communities; recommendation 9 – building partnerships – using networks; and recommendation 12 – unlocking Australia's full potential. The authors outlined a strategy that is considerate of the dichotomy present in that there are two distinct audiences when it comes to Australian deserts: those who are desert dwellers, and those who travel to the desert. This report aims to bring together the 'perspectives of people living in the desert and people with experience of science communication in desert regions of Australia to improving strategies, coordination, practice and results in this field' (p. viii).

Through a survey of more than 100 organisations and individuals involved in desert science communications, this EWG report sought to 'gather expert views on how science engagement can be enhanced in and for the desert regions of Australia' (p. viii), in addition to their views on the constraints and opportunities in this area. From this survey the authors proposed recommendations aimed at improving the nature, strategy and delivery of communication activities across the desert regions of Australia, guided by the IA principles.

From the survey data, the EWG identified overarching key principles to guide future science communication projects in the desert in order to maximise their effectiveness. The communication principles are separate to the report's recommendations in that they provided an action-based approach for practitioners to maximise the outcomes of science communication in the desert. All projects should have the 'aim of transforming the desert economy, environment or society in ways that improve wellbeing, prosperity and sustainability' (p. 13). Projects that follow these key principles should use existing networks, harness existing activities, knowledge, skills and resources, and where possible use two-way communication methods of communication providing opportunity for dialogue and participation. Despite the preference for two-way communication, due to the diversity and remote nature of desert communities the authors recommended a balance between face-to-face communication and the use of broad-scale mass communication models be found. Effective communication would include considerations of the diversity of languages in the desert communities and activities would ideally incorporate an evaluation process to demonstrate impact.

In addition to the key principles driving the communication activities the study highlighted key communication themes that are 'regarded as critical to the survival and prosperity of desert communities industries and people' (p. 13). These themes in no particular order are; water, energy, heath, biodiversity, Aboriginal knowledge and intercultural links, climate change, 'Desert syndrome' and the isolation of economic, political and social decision making on the deserts, mineral and mining operations, food and medicines in particular native plants, and improving ICT and the use of appropriate technologies in remote communities. The identification of these key communication themes by the authors enables a strategic approach to communication to occur.

The EWG retained motivations of dissemination of information where the authors stated that the public will 'benefit from more effective dissemination and use of scientific and technical knowledge' (p. 2). Yet, the authors discussed not only the importance of local knowledge, but also the need for two-way communication and not just the ‘one-way “science-push”’ activities (p. 6). The authors discussed that this is of particular importance when dealing with the Aboriginal communities and their local knowledge. They state that ‘effective communication is a two-way street involving interaction, dialogue, participation and exchange of knowledge and insights between desert people and those involved in science’ (p. 6).

The survey reported on the current use of the usual broad variety of science communication activities, ranging from one-way communication activities of public lectures, radio programs, websites, newsletters and fact sheets to two-way methods of ‘awareness’ activities, workshops, school visits and field trips. The authors outlined mechanisms to improve the effectiveness of science communication in the desert, stating that from the findings of the study that face-to-face interaction is the most effective way to communicate science, noting its logistical limitations. An equally strong case for the use of mass communications was put forward in order to reach the widely dispersed audience. However, social media was noted as the least effective method, chiefly due to the low access of remote communities.

In response to concerns raised in the study of lack of ‘cohesion, consistency, strategy, cooperation and clear direction for science communication in the deserts’ (p. 11), the authors proposed the formation of a national network of those bodies that are engaged in science communication in the deserts – the Deserts Science Network (DSN). The DSN will work with those individuals and organisations already involved in desert communication. The authors proposed that ‘desert regions be treated as a whole rather than state-by-state or via individual organisations’ (p. viii), due to the breadth of activities and organisations that are currently undertaken in relation to the deserts.

This report identified the importance of desert Australia due to the Aboriginal population and the role of deserts in the nation’s economy. It clearly outlined a way forward for science communication informed by consultations with the relevant stakeholders currently involved in science communication in the deserts. The authors proposed a method for selecting and prioritising science communication activities. The consultations highlighted the limitations of current activities, informed the development of key communication themes to guide future activity and compiled an extensive list of potential future activities across the deserts and beyond – the latter being identified as requiring further work to prioritise these activities.

The disconnect between the appeal of using digital technologies, as having great potential as it has the ability to cover great distances, and its limitations in reaching remote communities was a key feature of this report. Another key feature of the report was the importance of local knowledge. The authors remark on its value as deserts differ to the rest of the country

> environmentally, culturally, economically and physically. Their people depend critically on local knowledge and on relationships for their survival and prosperity – so it essential to engage them in the conversation about what knowledge they need and how best to apply it (p. 5).

The emphasis on the inclusion of local knowledge and dialogue with the community in this EWG report is reflective of the language of the IA strategy, but unlike IA is clearly grounded in actions to move forward. Through this report the authors presented a framework with the aim of developing a national strategy, facilitating stakeholder collaboration and identifying opportunities to improve and encourage science communication in the desert regions. Overall the report provides an informed strategy for future desert science communication, clearly articulating the goals, priorities and difficulties of what SEA Australia would look like with respect to the Australian desert.

Report 12: Inspiring Australia Expert Working Group on Indigenous Engagement with Science: towards deeper understandings

Inspiring Australia Expert Working Group on Indigenous Engagement with Science: towards deeper understandings (DIICCSRTE, 2013) has been developed, as part of the implementation of the IA strategy, in response to the need to maintain important Indigenous knowledge systems not only as an issue of science engagement, but as 'an issue of national significance for all Australians' (p. vi). The authors outlined that an important step in achieving this is

> understanding and valuing Indigenous knowledge systems, acknowledging the significant contribution (sic) that…have already [been] made to the development of science in Australia, and sharing this within the Indigenous community as well as the scientific and broader Australian community (p. vi).

The authors discussed how the Indigenous population is distinct from the rest of the Australian population in that Indigenous people largely live in remote or very remote areas, they have a different age profile, are less likely to be 'employed in Professional, Scientific and Technical Services than non-Indigenous people' (p. 1), and that Indigenous youth are still underperforming compared to non-Indigenous students.

The authors noted that broad consultation of remote Indigenous communities was beyond the scope of this EWG report, with the authors identifying this as an area for future work 'to ensure that the traditional knowledge holders…are able to participate in a meaningful way in augmenting and implementing the recommendations of this report' (p. vi).
The primary focus of this report is on the visibility and recognition of local knowledge, and that there is an 'urgent need to conserve and prevent further loss of Indigenous knowledge' (p. vi).

The authors noted that with 'rapid movement toward a knowledge-based economy in Australia and globally, it is imperative that Indigenous knowledge systems are appropriately acknowledged for the contributions they currently make, and appreciated for their capacity to contribute even more' (p. 4). As the authors reflected on the recent shift of western science, they commented that there has been significant shift towards seeking solutions within Indigenous knowledge systems in order to mitigate the impact of globalised industrialisation – in particular in the areas of environmental sustainability, climate change and global warming (p. 3).

In line with the IA report, the authors discussed the role of the media as a key method to deliver on the recommendations of the EWG report. The authors discussed that the media would not only to connect with the Indigenous communities in science, but also to inform the wider community about Indigenous science achievement and to 'create a new appreciation of the value of Indigenous knowledge systems' (p. viii) amongst all communities. Another parallel to IA is the emphasis on education as a key mechanism as 'education needs to provide a solid grounding in scientific literacy' (p. 1). In particular there is a strong focus on programs that engage Indigenous young people to encourage them into science and science-related careers – a motivation that parallels the IA strategy. Unlike the IA report, the authors did not discuss communication mechanisms, rather they talked about science engagement as a general term for communication.

The report is largely focussed on the preserving language and knowledge, changing cultural paradigms and the promotion and involvement of Indigenous Australians within universities, in research and governance roles. (p. 10). The authors outlined the need for enhanced participation by Indigenous communities in developing science and research agendas and initiatives:

> Indigenous perceptions of the value of science are greatly enhanced in programs where there is a dedicated effort by research organisations to ensure Indigenous participation in decision making about research design, conduct and outcomes, and to create post-hoc evaluation frameworks that consider benefits to Indigenous people (p. 15).

The report detailed the aim for greater integration of Indigenous priorities, and their involvement in the design, delivery and evaluation of science and research projects. The authors also highlighted the need for enhanced visibility through greater celebration and profiling of the Indigenous achievements in science.

This EWG report contributes to the understanding of what a SEA might look like with a specific focus on the role of Indigenous knowledge. The authors outlined the importance of local knowledge of Indigenous communities and the need to use this knowledge in conjunction with western knowledge to address primarily environmental issues and for the preservation of this knowledge and the language and culture that goes with it. Overall this report begins to articulate a strategy primarily focussed on raising awareness of the importance of Indigenous knowledge and culture to Australia, describing a future of science engagement in this area.

Report 13: Science for Australia's Future: Inspiring Australia, A Review of Initiative 2013

A recent unpublished report reviews the *Inspiring Australia Program – Science for Australia's Future* (IA program)(DIISR, 2014). The IA program was commissioned in 2010 to deliver on the IA strategy articulated in the original 2010 report. The IA program received $21 million in funding over three years with the remit of 'providing leadership, driving strategy and delivering programs to improve the quality of science communication, the breadth of deliver and its impact' (p. 4).

In essence this review reports back to the Australian Government on its investment to date in the IA program through assessing its achievements against the Department of Finance's six program evaluation criteria (appropriateness, effectiveness, efficiency, integration, performance assessment, strategic policy alignment), and against the goals articulated in the IA strategy. Largely this report is an internal government review, however it does report on the outcomes of the IA program thus far.

The authors reported that significant progress has been made against 12 of the 15 recommendations of the IA strategy, with the programs reaching 1.7 million Australians annually.

The authors reported on the notable achievements delivered under the IA program. Namely, six EWG reports were commissioned to further expand on specific recommendations and priority areas of the IA strategy. These tailored strategic approaches to six areas of industry-focussed and regionally-based science engagement through the EWG reports, critiqued earlier in this chapter.

Recommendation 13 of the IA strategy described the 'national framework – local action' approach to deliver the establishment of a network of IA officers in each state and territory. In support of this framework and the establishment of the coordinated approach to science communication, Questacon took on the leadership role through the administration of the IA program, working in conjunction with advisory groups and IA Officers across the country, with the aim of future work to expand this network into industry.

Again, the use of the media was a strong focus of this report, in particular greater support for science journalists by embedding research scientists in traditional media outlets for a periods of time, the use of new media through the creation of online hubs of resources for journalists, online courses in journalism for scientists, the trial implementation of science journalism training at the University of Queensland, and programs for secondary school students that encourage the critique of current news media.

In terms of program delivery the authors reported on the following projects undertaken as part of the IA program. The primary project was the establishment of a competitive grants scheme, ‘Unlocking Australia’s Potential’. This scheme made $5 million available for science communication projects to address the principles of IA and reach ‘Australians who, due to geography, ethnicity, age or social circumstances, might not have been interested or able to engage with science’ (p. 18). This initiative speaks to the key audience group as defined in the IA strategy as those that are not already ‘engaged’ with science. The authors reported on the success of this initiative that funded 63 projects, reaching an estimated 1.5 million Australians. Other primary initiatives reported on include; ‘National Science Week’, the annual celebration of science in Australia comprising of over 1850 events, reaching 1.5 million people with a budget of $1.25 million, and the Prime Minister’s Prizes in Science and Science Teaching, now managed by the IA program.

In addition to these projects the authors note the recent involvement of the IA program in supporting Science and Technology Australia in the delivery of their annual Science Meets Parliament event, that brings over 200 ‘working scientists to Canberra for a two-day program of professional development and networking aimed at helping them better communicate their science to the media, policymakers and parliamentarians’ (Science and Technology Australia, 2015, para. 1). With the exception of the grants scheme these are pre-existing initiatives rebranded under the IA program.

This review reported on the framework of principles established ‘to guide policy development and program implementation for science communication initiatives at a national and state level’ (p. 9). The framework set out to: define and improve standards; promote consistency of best practice; optimise appropriateness, effectiveness and efficiency; and increase accessibility. It proposed 10 high-level principles and guiding considerations for science communication initiatives, six aimed at science communication practitioners and four guiding government involvement. The framework presented an overarching and general direction, with statements such as ‘[a]n appropriate evaluation strategy is employed’ (p.3) or ‘[a]ccessibility and delivery mechanisms appropriate to the target audience are incorporated’ (p. 2). The specifics of what initiatives or practices that should be employed are not presented as part of this framework.

Despite these limitations, the framework began to articulate what is expected of communicators in achieving the aims of the IA strategy, illustrating those elements that are considered important to achieving a SEA.

In addition to this framework the authors make reference to the creation of a 'science engagement toolkit' by the IA program (Science, 2015). Created under the remit of the IA, this toolkit furthers the IA strategy by taking the practical steps in compiling online resources for science communication practitioners, scientists, journalists, and policy makers. The creation of a central repository furthers the aims set out by the IA strategy, by providing practitioners with the tools to enhance their skills in delivering improved communication activities. This toolkit is largely focussed on the media. This is reflective of the commentary in the IA strategy, the subsequent EWG on the media and this review of the IA program, all which have a significant focus on the role of the media in achieving the aims of creating a SEA.

The review report identified the three key communication groups of youth, Indigenous, and regional and remote Australians, where the topics of agriculture, internationalisation of Australian science and the youth were identified as priority areas of the 'Australian community and economy which are 'in need of improved science engagement' (p. 34). Any definition of 'engagement' was not part of the discussion of this report.

The authors outlined a long list of proposed future activities for the IA program underpinned by the need to continue the 'national leadership – local action' framework with the expansion of IA officers in each state and territory across Australia. They proposed the establishment of IA as a quality-assurance brand, and the continuation of the existing programs National Science Week and the Prime Minister's Prizes for Science. The authors discussed the establishment of new programs of 'citizen science, science tourism, science clubs and national branding for IA' (p. 38). Of these four, citizen science was deemed the most suitable program by the science community with the most immediate potential for return on investment.

The authors reported that the review was motivated by the desire to 'improve the nation's economic and social wellbeing into the future by strengthening its commitment to science engagement in this country…[through the] provision of leadership, strategy and programs'. Under this framing the authors reflect on the achievements of the IA program over the last three years, concluding that the IA program is 'better positioned than any other organisation or program to continue meeting those needs in order to build a future for Australia inspired by science' (p. 42).

Chapter summary – definitions and aims of engagement

Inspiring Australia has the potential to influence Australian science communication agendas through establishing a new set of policy standards and funding opportunities. As it stands the IA report itself does not identify the next steps for science communication, rather, it proposes the creation of EWGs to address specific recommendations. These six EWGs established as part of the implementation of the IA strategy expand on the original strategy, with some EWGs directly addressing key recommendations of the IA report. The EWG report *Science and the Media* focuses on the future of science journalism with respect to traditional 'old media', identifying strategies to improve the relationship between scientists and the media with tactics to make journalists' jobs easier. The later EWG report *Developing an Evidence Base for Science Engagement in Australia* closely parallels the original IA report particularly in terms of its language and structure. This report is concise and focussed on three main themes – evaluation, coordination, and funding. It described a diverse nation as it identified Indigenous Australians as a priority communication group and the new media as an essential communication mechanism in reaching a diverse and disparate population. *Science Engagement into and for Australia's Tropical Region,* details the need for greater involvement and consideration of tropical science communities in Australia's science agendas, with a particular focus on the disadvantage of tropical Australians compared to those in the southern states. A key focus of this report is on scientific literacy and formal education, with the aim to encourage more students into science careers, and the role of local knowledge as a key feature of tropical Australia. The report identifies high-level science messaging that relates to tropical Australia of 'climate change, food and water security, energy and the health agenda'. The EWG on *Marine science: a story for Australia* outlines the unique benefits the marine sector brings to the nation and the environmental responsibilities this sector carries. A primary focus of this report is on raising the public's awareness and understanding of the marine environment, and identifying key themes to guide future communication activities. This report discusses the important role of community and cultural institutions in achieving these aims, yet retains a strong focus on the formal education sector. The EWG report *Inspiration from the Deserts: Science Engagement in and about Australia's Desert Regions* discusses the importance of desert Australia to the economy. It articulates a detailed strategy, guiding principles and key communication themes for future action. A particular focus of this report is on the importance of local knowledge of Indigenous communities and the role new media, its ability to reach the diverse population and its limitations in relation the lack internet access by remote communities. The EWG on *Indigenous Engagement with Science: towards deeper understandings,* focuses on the importance of local knowledge of Indigenous communities and the urgent need to increase the visibility and recognition of Indigenous knowledge systems, and its role in working with western science to address areas of environmental sustainability. The final report reviewed here was the (unpublished) 2013 review of initiative *Inspiring Australia Program – Science for Australia's Future*. Differing from the other IA reports, the 2013 review of initiatives is internally focussed as it reflects back to the Australian Government, against specific evaluation criteria, on its investment to date in the IA program.

The reports critiqued in this chapter all contribute to Australia's science communication strategy with the aim of achieving a SEA. These reports vary in quality and precision in defining the key terms yet together illustrate the current science communication agenda in Australia, as one that is driven by the desire for improved societal outcomes, both for the individual and for society as a whole. The initiatives of IA will result in the use of science by the public not only to inform their decisions but to also inform public debate, enhanced decision making, and the early adoption or support for emergent technology by the public.

The IA strategy is underpinned by the desired outcome of an increase in school students continuing to study science into university and going on into science careers within Australia – supporting the notion of 'home grown' scientists. The IA strategy targets school students, and their teachers, as the primary audience. Other integral audiences identified under this strategy include those considered not already engaged and, to a lesser degree, Indigenous communities and those for whom English is a second language.

In delivering on the aims of IA one-way methods of communication dominate, in particular the media, new media, and formal schooling. The language used throughout the reports implies the use of newer more participatory methods of communication through 'public engagement', yet on closer inspection the term is used in a variety of ways and often as a synonym for 'communication'. Citizen science initiatives were identified as the key 'engagement' mechanism under the IA strategy, a decision largely motivated by economic factors. The following summary of the emergent themes details the evolution from the initial IA report through to its subsequent EWG reports, detailing both the similarities and differences in the themes and priorities that have arisen from the reviews.

The similarities can be categorised under the following five themes:

1. Drivers and motivations:
    - The 'national framework – local action' approach to science communication narrative is carried throughout the reports
    - Economic motivations – science communication initiatives are largely underpinned by motivations of economic concerns
    - The importance of local knowledge systems to achieving the aims of a SEA

- The key areas of interest focus on the environmental and health sciences

2. Audience:
   - The community/general public were continually identified as the primary audience group
   - School students, Indigenous communities, and rural and remote communities were identified as key audience groups
3. Mechanisms:
   - Mass (broad) communication was identified as a primary mechanism, in particular the mass media and new media
   - The formal education system featured heavily as a key mechanism
   - Greater use of existing science communication enterprises including science centres, museums and existing community programs were highlighted throughout
   - Citizen science initiatives were identified as having a primary role in delivering on the communication aims, noting its appeal relates largely to economic motivations
   - Use of two-way communication mechanisms of dialogue and participation were identified as a key mechanism, yet motivations of the dissemination of knowledge and other one-way mechanisms persist throughout the reports
   - Call for formalised communication requirements as part of research grant funding and the greater investment by government bodies in science communication initiatives and research
4. Outcomes:
   - Enhanced community engagement as the primary desired outcome
   - An increased number of students studying science subjects in later years and going on into science based careers.
   - Increased scientific literacy in the public
   - Participation in decision making and informing policy development by not only the public but also governments and business, with a particular emphasis on evidenced-based decision making

The differences can be categorised under the following three themes:

1. Drivers and motivations
   - Concern that a disproportionate amount of effort is focussed in southern Australian, leading to ‘perverse outcomes’ as stated by the authors of one report
   - One review called for the decentralisation of programs and initiatives in direct contrast to the ‘national framework - local action' approach outlined in IA

- Suggestion made by one report that the public is deficient and unable to effectively participate in scientific decision making

2. Mechanisms:
   - In contrast to the recommendations of IA and its EWG reports; social media and digital technologies were identified, in two EWG reports, as being the least effective method to communicate for those living in remote communities
3. Indigenous communities and diversity:
   - Rather than simply acknowledging local knowledge systems; local knowledge, language and cultural paradigms also need to be preserved and integrated into the SEA strategies. This includes the promotion of Indigenous Australians within universities, research and governance roles

The greatest shortcoming of these reports is in their use of the term 'engagement'. Understanding what is encompassed under the term 'engagement' is essential in creating an understanding of what a SEA would look like. Of particular interest to this thesis is how the term 'engagement' is defined and used throughout these 13 reports. What is apparent from these reviews is that the term 'engagement' is often used as a catch-all description of science communication activities that seek to 'engage' with the public. Broadly, there is no uniform definition of the term 'engagement' across all 13 reports, with the exception of the IA report and its EWG report on *Developing an Evidence Base*. How the term 'engagement' is used throughout these reports is of relevance to creating a picture of understanding of what a SEA would entail. To address this, the methodological approach based on the principles of grounded theory were applied. Unlike other methods of analysis, grounded theory enables the nuanced comparison of how specific terms are used, their meaning and in what context (Hallberg, 2006; Howard-Payne, 2016; Jeon, 2004; Lo, 2016; Ong, 2012; Ruppel & Mey, 2015; Smith, 2015; Walsh et al., 2015; Whiteside et al., 2012). The process employed here used key-word-in-context analysis of the use of the term 'engagement'. This technique required every instance of the term 'engagement' to be recorded along with the context in which it is was used. This process enabled greater clarity over the use and the meaning of the term 'engagement' to be obtained, and from this a series of underlying categories began to emerge. These categories were continuously compared and refined throughout the process. What finally emerged from this study were five categories that summarise current policy-level thinking about science engagement as represented in the following schema:

1. 'Us'; who will be undertaking the communication, where and when
2. Communication; mechanisms or methods of communication with the public
3. 'Them'; in defining who the audience or communication partner group is, where and when communication should occur

4. Process; as an outcome of the communication process what the resulting behaviour of the public will be
5. Goals; what the desired outcomes, aspirations and aims of the communication process are

These five broad categories provide evidence of emerging participatory or two-way practices by reflecting the context of how the term ‘engagement’ was used. This informed the development of the following model, see Figure 6, that details the key elements under each category. Figure 6 highlights that not only that communication remains a top-down approach that uses predominately one-way methods of communication. It also details the vast array of perceived different benefits that will emerge from this process resulting in positive public change.

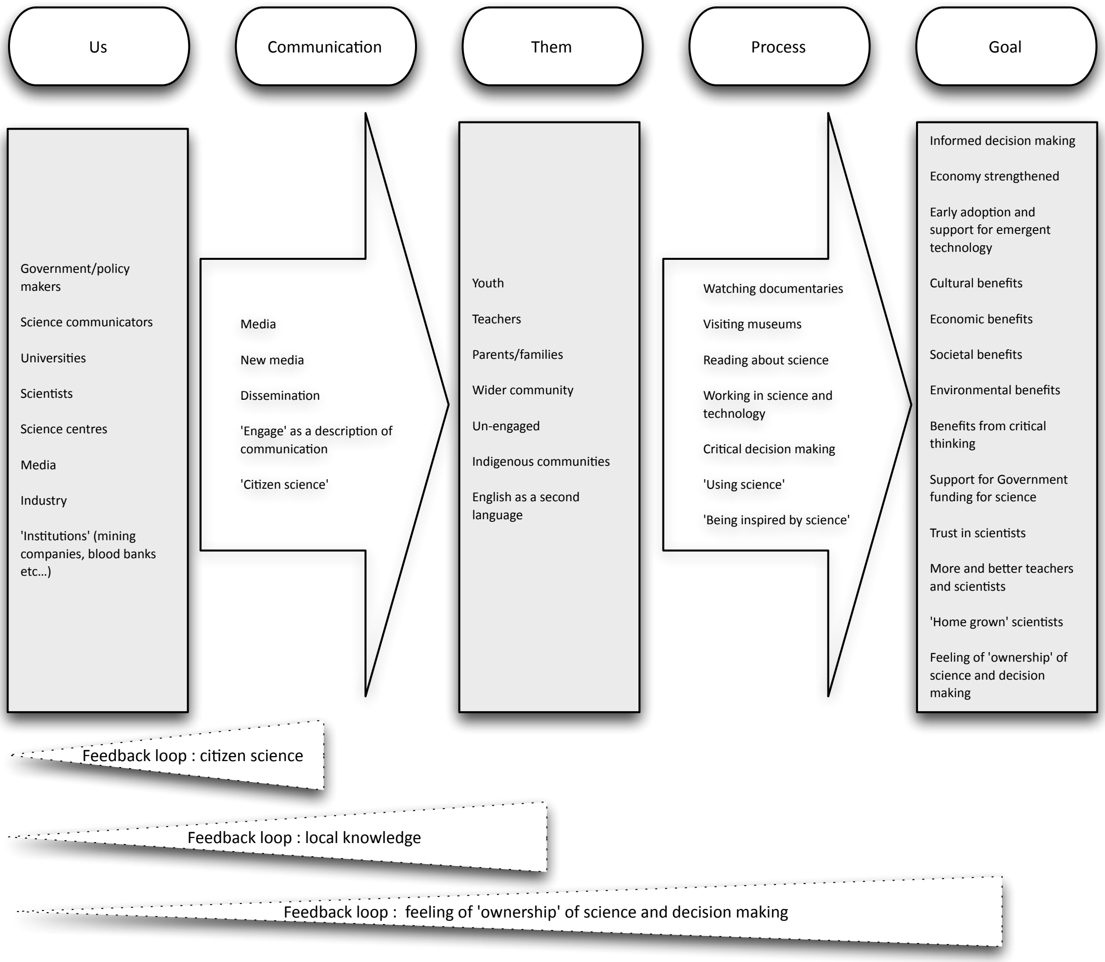

Figure 6. A schematic of the how the term ‘engagement’ is referred to throughout these 13 government reports.

This audit highlights that instead of just wanting to educate, raise awareness, increase interest in, and change attitudes towards science in the public, the new era seeks to do all this and also ‘engage’ with the public, resulting in many additional benefits. Such benefits include: enhanced economical, societal, and environment benefits, though these are not elaborated on in detail in the reports; improved critical thinking and decision making; the early adoption of technology; and more students studying science and moving into science careers, with the emphasis on 'home grown' scientists. To achieve these goals, two-way and participatory methods of science communication are proposed in addition to one-way mechanisms of communication.

The language used throughout the reports implies the use of more participatory methods of communication, describing a softer and more inclusive approach to communication and public involvement in the process. However, fundamentally the communication outcomes are still focussed on the public changing (specifically improving), not science. However, a marked shift in the rhetoric can be seen in the recent EWG reports. There is evidence throughout the reports in the language used that suggests a shift towards more participatory initiatives, largely in the EWG reports with the discussion of grassroots communication. These EWG reports are largely driven by economic outcomes. As a consequence of these motivations the practical steps towards knowledge sharing can be seen – in particular the importance of local knowledge in the areas of tropical, marine and Indigenous communications.

Economic motivations are also apparent in the IA strategy and its EWG reports. The overarching vision of IA's 'national framework – local action' approach to science communication called for greater coordination of activities and effort to both coordinate the messaging and to enhance the effectiveness of communications by minimising duplication of effort. IA strategy also outlined the explicit aim of increasing the return on, and safeguard the future of, investment in science. The majority of the EWG report topics were all centred around, or had direct links to, the nation's economic standing; in particular, the areas of agriculture, mining, fisheries, tourism, and Indigenous knowledge of the land and environment and how it relates to the aforementioned industries. The link between science, innovation and technological development was made explicit throughout the IA strategy, with an emphasis on not only society's uptake of new technology but also its production and how this relates to the Australian economy and the notion of 'home grown scientists'. The IA strategy and its EWG reports outline the goal to raise awareness, increase interest in, and to change the publics' attitudes towards science – motivated by societal outcomes – not just economic factors.

As it stands, the IA strategy as articulated in these reports is predominately aspirational, describing a broad, and generally one-way, approach to science communication in Australia. The strategy in its present form highlights the authors' vision of what it is they want to achieve, yet the authors are unable to articulate how it is to be attained.

CHAPTER 5 – INVESTIGATING THE VISION OF A SCIENTIFICALLY ENGAGED AUSTRALIA BY LEADERS IN AUSTRALIAN SCIENCE POLICY

This chapter seeks to extend commentary presented in Chapters 2 and 4 in relation to the current perspectives on PE by science communication professionals and academics, and the policy development around the IA strategy. Here I triangulate the perspectives on a SEA from the perspective of key leaders in the Australian science policy and science communication communities. Their perspective adds another dimension to the discussion thus far. The interviewees have either directly informed the development and/or are primary stakeholders of the outcomes of the IA strategy. I sought to understand their opinions and perceptions of science communication in Australia, from this the emergent themes I uncovered provide insight into the motivation behind the creation and implementation of the IA strategy and our understanding of what the aim of a 'scientifically engaged Australia' might look like.

Participant selection

The participants selected for this study have been chosen as they are leaders in their respective organisations, prominent figures within the scientific community, and involved in science-policy discussions in relation to the national science communication agenda. In addition, many of the participants had direct input into developing the IA strategy. The participants were selected as their views and visions matter in a very direct practical sense, if we are to understand what a scientifically engaged Australia means for individuals, for governments, for researchers and for science communication practitioners.

The participants included:

Professor Ian Chubb AC, Chief Scientist for Australia (hereafter referred to as IC)

Professor Chubb is a key figure in not only the science sector but also in the higher education sector as previous Vice-Chancellor of The Australian National University. In his current role as Chief Scientist he is responsible for providing high-level independent advice to the Australian Government on matters relating to science, technology and innovation (Office of the Chief Scientist, n.d.).

Professor Aidan Byrne, CEO, Australian Research Council (AB)

The Australian Research Council (ARC) is a Commonwealth entity that advises the Australian Government on research matters, with a mission 'to deliver policy and programs that advance Australian research and innovation globally and benefit the community' (Australian Research Council, 2014b, para. 2). Professor Byrne as CEO has oversight of the management of the 'National

Competitive Grants Program, a significant component of Australia's investment in research and development, and has responsibility for Excellence in Research for Australia' (Australian Research Council, 2014b, para. 1), and is responsible for an annual budget of just over $900 million (Australian Research Council, 2014a).

Professor Warwick Anderson AM, CEO, National Health and Medical Research Council (WA)

The National Health and Medical Research Council (NHMRC) is a Commonwealth entity that is 'Australia's leading expert body promoting the development and maintenance of public and individual health standards' (National Health and Medical Research Council, 2015, para. 1) with a mission of 'Working to build a healthy Australia'. Professor Anderson has responsibility for bringing 'together within a single national organisation the functions of research funding and development of advice' (para. 2), drawing upon the resources of all components of the health system, from governments, to heath care professionals, researchers, program managers and the community. He is responsible for an annual budget of just over $1 billion (National Health and Medical Research Council, 2013).

Professor Graham Durant AM, Director, Questacon - The National Science and Technology Centre (GD)

Professor Durant oversees the operation an interactive science centre guided by the vision of 'a better future for all Australians through engagement with science and innovation' (Questacon, 2014, p. i). Questacon boasts more than 200 interactive exhibits, 200 staff and over 400,000 annual visitors to its Centre in Canberra, with an additional 110,000 visitors reached through Questacon's travelling outreach activities and an annual turnover of over $33 million (Questacon, n.d.).

Ms Catriona Jackson, CEO, Science and Technology Australia (CJ)

Ms Jackson was selected to participate in the study based on her current role as CEO of Science and Technology Australia; the nation's peak body for science and technology, representing 68,000 scientists and technologists to promote their views on a wide range of policy issues to government, industry and the community (Science and Technology Australia, 2013). Ms Jackson also has extensive experience as media and science journalism. Her previous roles include; the Director of Communications at The Australian National University, and press secretary to Senator the Hon Kim Carr, in his time as Minister for Innovation, Industry Science and Research.

Dr Anna-Maria Arabia, Chief of Staff to the Hon Bill Shorten, Leader of the Opposition, previous positions include General Manager, Strategy and Partnerships, Questacon, and CEO, Science and Technology Australia (AMA)

Dr Arabia was selected to participate in the interviews based on her extensive experience as a professional science communicator, including as CEO of Science and Technology Australia, and in her work in managing the IA strategy and partnerships program at Questacon.

Additional participants were identified but either declined to participate or did not respond to the invitation.

For ease in reading, the following narrative and discussion uses the interviewees' initials rather than their full names, as detailed in parentheses above.

This sample size for this study was small and targeted with the intended participants selection based purely on their role in the Australian scientific and policy-making community.

Method

The methodological approach to this research is qualitative and was selected as the most appropriate considering the project aims. Ethics approval for the study was obtained from the Human Research Ethics Committee granted on 15 October 2013 protocol 2013/446.

Invitations were sent to potential participants by letter briefly outlining the study, seeking their agreement to participate and asking for the contact details of the relevant staff to assist with the meeting arrangements at a time and place convenient to them (see Appendix E). Follow-up contact to their offices was through a combination of telephone and email.

As per the ethics guidelines written consent was obtained prior to the interview (see Appendix F). As part of this process the participants were informed that the study sought to collect and report on personally identifiable information including their names and positions. Participants were provided with a copy of the consent form for their records. As the participants were public figures they were allowed the opportunity to review and edit their interview transcript and were able to withdraw from the study up until the final stages of analysis. At the beginning of each interview after written consent was obtained I briefly introduced the purpose of the study by way of the following brief background statement:

‘As you are already aware, the overarching goal of the Inspiring Australia report is to deliver a national strategy for engagement with the sciences, with the aim to deliver a more scientifically engaged Australia’.

The format of the study was a half hour to an hour-long semi-structured interview seeking their views on the following five key questions:

Q1. Do you think it is it important to achieve a scientifically engaged Australia?

Q2. What would a scientifically engaged Australia look like?
Prompt for further information in terms of the following sectors:

a. For Individual members of the Australian community?
b. For (local and national) governments in Australia?
c. For universities?
d. For the education sector beyond universities?
e. For the business community?
f. Other sectors?

Q3. How or through what mechanisms could this [a scientifically engaged Australia] be achieved?
Prompt for further information in terms of the following sectors:

a. For Individual members of the Australian community?
b. For (local and national) governments in Australia?
c. For universities?
d. For the education sector beyond universities?
e. For the business community?
f. Other sectors mentioned in question two?

Questions 2 and 3 were assisted by a visual prompt listing the aforementioned six sectors (see Appendix G).

Q4. a. Who do you think is responsible for this undertaking, to achieve a scientifically engaged Australia?
b. What kinds of responsibilities should different sectors carry?

Q5. The academic and government literature suggest that one-way models of communication (such as public lectures, displays, blogs, newspaper articles or television programs) about science are no longer adequate. Yet they remain the most common models used by people actively involved in communicating science.

a. Do you think this discrepancy between the ideal and reality is a problem?

b. Why do you think the discrepancy exists?

The interviews took place over the period November 2013 to April 2014. Each interview was digitally recorded and transcribed verbatim, preserving grammatical idiosyncrasies, with the exception of the deletion of ‘ums and errs’ that did not seek to advance the narrative. The interviewees were given the opportunity to review the transcript and modify as necessary. Some participants elected to review their transcript, and the reviewed version has been used in the following data analysis.

The formal method of data analysis employed was guided by the principles of grounded theory first developed by Glaser and Strauss (1967). As an iterative process of analysis, it preserves the nuances of the interviewees’ responses, enabling the identification of multiple emergent themes from the discussions. This study employed Glaser’s classic grounded theory approach due to its realist undertones and higher degree of methodological flexibility (Hallberg, 2006; Howard-Payne, 2016; Lo, 2016; Ong, 2012; Smith, 2015). This qualitative approach is ideal in managing the complex and interconnected data of a real-world situation such as this. This process allows for themes to emerge, and for categories to be constructed and continuously refined as they emerge from the data. From this process three main research questions were identified of 'what would SEA look like?', 'how do we get there?', and ‘is there a discrepancy between theory and practice?’ and are used as the basis for the following thematic analysis of the data. The interview transcripts were first coded against the three research questions, and then the responses grouped under each research question were analysed to identify the emergent themes from the discussions.

The following narrative presents the interviewees’ discussion and the emergent themes under the three research questions of 'what would SEA look like?', 'how do we get there?', and ‘is there a discrepancy between theory and practice?’.

Research Question 1: 'What Would SEA Look Like?'

Interviewees’ answers to the research question ranged across a number of topics, which I have broadly grouped into four emergent themes. The interviewees did not all agree about what a SEA would look like, so did not all contribute statements to every theme. Under the first theme I grouped the interviewees’ statements about the inherent importance and value of science. The second theme emerged from several interviewees' beliefs about the relationship between science literacy and improved decision making. The third theme encompasses the interviewees' views on the government's investment in science, the complexities of scientific policy and political decision making, and the role of science in the nation's economy. The fourth theme discusses the interviewees' perspectives on the community of science, its role both nationally and internationally.

Theme 1: the inherent importance of science

The general consensus from all interviewees is that science is inherently important. They all commented in some way that science is universal, of value to and underpinning much if not all of society. Some such as AB provided straightforward support with the statement 'I think it's very important' and that 'it's in the nation's best interest to have a strongly engaged research and science research community'. CJ supported this sentiment with the added justification that 'it is really important that people are scientifically engaged because virtually everything we do has a connection with science' and 'we simply couldn't function without science'. Others argued its importance based on societal measures; GD claimed that science has a 'corporate social responsibility', CJ stated that it is 'the foundation of a modern civilization', and WA commented how 'it is just a mark of an advanced, sophisticated, liberal democracy that the population understands science because science is probably the biggest driver of change in their lives'. IC elaborated further about the societal benefits of science by commenting on the role of science into the future and how 'the real issue is that not enough Australians are engaged with science and since science plays so much a part of their lives right now, as well as off into the future in ways we can't easily predict'.

The motivations behind the importance of science range from idealistic to pragmatic. Those with idealistic views such as CJ outlined a view of a SEA where in 'the ideal you would have is a country that understands the worth of science to the same extent that we understand the worth of sport'. GD offered his own idealist view in support of science as he stated that

> if nothing else it just makes the world a more wonderful place to have that deeper understanding of the world you live in…[and that] all of these things help create a sense of interest and wonder, and it enriches lives socially, culturally, and so it is not just about education and economy.

AMA shared GD's opinion, describing the ideal of a more SEA an 'informed, prosperous, healthy society'. CJ added to this narrative with the statement that ideally the Australian public will 'have faith in science, and faith that science is a good and extraordinarily important process'.

Many interviewees did share views that are both idealistic and pragmatic. While CJ appeared more idealistic than her colleagues with her prolific aspirational statements about 'faith in science', AB offered the most commentary on the pragmatic benefits of science. He shared his opinion that a SEA public would 'understand why, why we do science…and what the community should be aware of is the benefits that science and research in the broad brings to people'. All interviewees mentioned the importance for the public to understand the benefits that science can bring and the relationship between science and technological and medical development. The pragmatic benefits in health and medicine were of note by AMA in her remark that

> I would sometimes eat food that is unhealthy; I know that the evidence says that that is unhealthy, but I do that knowingly. Rather than eating food that is unhealthy all the time completely oblivious to nutritional value, as, for example. So an informed decision, a society that is able to make informed decisions.

Here AMA made note of the societal benefits of improved health, from informed decision making in terms of preventative disease, and in terms of population health issues such as the 'tropical diseases or dementia, diabetes' mentioned by AB. AB went on to describe how a SEA would be an 'Australia [that] can take advantage of the developments in science and indeed in research'. All interviewees used the mobile phone as an example of science informing technological development, which is of benefit to and embraced by society. CJ made direct reference to this relationship in her statement that 'virtually everything you do has a connection with science…my telephone and the guy that invented wireless connection'. In contrast, AB phrased his support from the perspective of the mobile phone not the individual, with the comment that 'I suspect Australia's uptake of technological devices like that [mobile telephone] is one of the highest in the world…and if you think about [it] the embedded science and technology in a device like that is absolutely enormous'.

Due to the widespread adoption of technology there is an implied notion that deep down the Australian public do know the value of science, although the interviewees did not acknowledge this explicitly. AB was the exception as he explicitly shared his view that society is not complacent and that 'as a whole actually has some sort of awareness and understanding of engagement if you like of what science and research can actually bring'.

The interviewees' commentary suggested that science is of value not only in its relationship with technological developments and societal benefits but also with the community, business and the education sectors. The value of science in underpinning the business enterprise was not always immediately evident; GD made the argument that 'science and technology can underpin how you run your business as much as being what business you're in' and IC shared a similar view of the importance for the 'business community to recognise that its future depends on scientific and technological advance in many instances'.

More so than science and business, all the interviewees highlighted the relationship between science and the public as an important area, with a particular focus on public understanding, education and scientific literacy as being inherently important. GD emphasised science's inherent importance for a 'whole raft of reasons…education, economy, understanding of science, how it works and the things it can and can't do'.

A prominent theme that emerged from all interviews is the shared sentiment, reminiscent of the PUS era of science communication, that the public requires education to improve their understanding of science. CJ remarked that 'there is not as much understanding as there could be in the community'. Others who shared this view were not as explicit as CJ, as she added 'I think it is really important that people are more scientifically engaged and have a better understanding of fundamental principles'. For some, support was implied. Others such as GD mentioned understanding as part of a specific end goal in relation to trying to gain community support for initiatives, stating:

> it is not about managing propaganda…these days you've got to bring communities with you if you want to exploit, and I use that word generally, forests or marine resources or energy resources or subterranean gas resources, you've got to bring the community with you in terms of raising their level of understanding of what it is, what the issues are. Often removing misplaced fear about certain things, flagging up areas where there are still genuine concerns.

Understanding can take many forms for GD. He commented that an ideal model of the public is one that is able to use the 'internet and the media, [knows] how to understand stories about science, and this is of course an ideal world and we are far from there at the moment'.

Unlike the other interviewees, AMA did not focus on the public's ability to understand scientific facts and figures. Her views on public understanding focussed on

> an understanding of having ideas, testing those, evaluating those and doing so in a kind of…you know the value of doing that in a systematic way is something that would enable the education sector to put its best foot forward in terms of helping society.

AMA saw formal education providers providing experiences that demonstrate the value of and an understanding of the scientific endeavour where 'you speak to a three year old around testing ideas, and retesting ideas and trialling and that's the beginning of that [scientific] process, and you can do that way into university beyond the sector and TAFE sector'.

Primary, secondary and tertiary education institutions and universities were identified by all interviewees as being responsible, at least in part, for generating understanding in the public. The formal education sector was subject to much commentary by the interviewees. It was seen as a crucial part of achieving a SEA, as the primary mechanism that can create a positive image of science. While all interviewees shared this view, GD and IC were the main proponents of this argument. GD provided an overview of how he sees the role of the formal education system, stating that it ‘plays an important role in firstly informing, inspiring, motivating, training, tutoring, facilitating learning of students at every stage, of identifying potential in young people’. IC shared this opinion, with the view that

> the real turning on and off about science happens early in schooling…so if science is poorly taught, boringly taught, didactically in the early years then more people will be turned off than maybe would have the capacity and the interest to study science if they had been taught inspiringly.

All others commented specifically on the quality of education, although no two opinions were the same. WA reported that the perceived decline in the quality of science education in primary and secondary schools has recently been addressed, stating, ‘in the last 5-6 years there has been an increase in attention through the Academy of Science and the Chief Scientist and others, on the sort-of slippage of science in high schools and primary schools – so that is good’. His views differed from AB who stated that the ‘development of curricula has a reasonably good focus on scientific literacy, not necessarily research, but again I think they have been embracing discovery-led learning in primary schools for a long time and that’s part of scientific methodologies’. AMA also discussed the role of inquiry-based learning with the view that ‘teachers who also understand the value of that [scientific] process, are able to teach it’. She went on to make note of the importance of ‘an education sector that has teachers who are qualified in the subject matter they’re teaching’. CJ talked about the quality of the Australian formal education system; she made reference to the flow on effects that good formal education has for the community, specifically in relation to the difference in opportunities between rural and metro environments. She argued that metro environments, specifically Canberra, already have a good public education system that presents opportunities to students and that these experiences are

> spread out to the rest of the community so you do have a community that is engaged and that’s supportive of science and that sees it as a really good job, that not just being a doctor but being a scientist is a really good thing to do.

A key feature of the relationship between primary, secondary and tertiary education is related to the recruitment of students into university. AB put forward his view of this relationship with his belief that there exists a strong relationship between secondary and tertiary sectors, as he remarked that 'there's a strong feeding from the secondary sector to the tertiary sector…[in the] connection to establish a pipeline so it's a connect as a pathway for students to come into the system'. WA outlined the importance of secondary teaching in enabling and providing students with adequate skills to be able to study the sciences further at university. He commented, 'so, we want enough high school students graduating with science subjects at a high level, we want enrolment of really good students in the sciences at university – science very broadly defined as including science teaching'. IC made a similar comment in relation to the education sector, including universities 'as being part of a concerted effort to encourage people to think about science even if they didn't want to study science, and at the moment they don't do that'. GD made a similar statement in relation to the importance of education, articulating education's 'important role as not only the supply chain for future scientists, technologists, engineers, mathematicians, but in fostering that love of learning of science generally and in helping students to develop as the scientifically literate citizens that we need'.

Scientific literacy is closely related to the public's understanding of science, and the notion of scientific literacy as an important outcome was raised by AB, WA and IC. When discussing the role of universities and the tertiary sector, AB noted that 'it's more interesting to think about scientific literacy...[and how] scientific literacy might then map across to some other parts of the tertiary sector into some more vocational training ones'. WA presented a different perspective on the importance of scientific literacy, interpreting the question of greater scientific engagement as stating how 'for the majority of Australians their engagement would be extremely minimal, but certainly a more scientific literate [public] that understood a little more when things are based on evidence and when they are not' would be of benefit and would enable organisations such as the NHMRC to assist the public in their decision making. Whereas IC, in response to this question, commented that in a SEA Australians 'would have a much higher level of scientific literacy and understanding [than at present] across the community as a whole'.

The role of universities was the subject of much discussion by the interviewees. Their primary belief is that universities are the main propagators of research, yet they also have a central role in science education and training of scientists. GD remarked that universities 'exist to conduct research, and to conduct training, tuition, and the balance of those activities largely governs what a university does, [and] will vary from university to university'. IC put forward a similar statement in that 'universities should be educating people, both scientists and non scientists, with a capacity to understand how science works, and they should be encouraging people not studying science to understand how science works'. AB provided a holistic view, stating that there is 'a deep and intimate relationship between university education and research in universities. Universities are vehicles of research, but they're also vehicles for training the next

generation'. AB extended his argument to include the view that 'there's an intimate link too between what should happen in that vocational training sense in some other tertiary institutions other than universities'. He went on to discuss his belief that universities do not have all the responsibility, and other tertiary education sectors also have a role, and 'that they should be anticipating likely changes in the future in the same way that universities are'.
Despite the overwhelming discussion on the importance of formal education and understanding among the public by the interviewees, there were those who felt that the public's understanding of the value of science is more important that the public's understanding science. This was evident when CJ discussed what are considered 'wicked' and societal problems that scientists are working on. She stated that

> not everyone wants to understand every detail about how the telephone works…But an understanding that science underpins all - that is, I think, really important, and it is really important when really serious issues like climate change or water or really nasty big issues come up, because people need to have faith that scientists are doing, are honest, genuine people who are working really hard to work out how on earth the world works.

Theme 2: enhanced outcomes from improved scientific literacy

The interviewees all made note of enhanced outcomes they thought would stem from improved scientific literacy, not only for the public, but also for governments and the business community. The outcomes that emerged from these interviews include: improved decision making ability resulting in better decisions, better information seeking behaviours, and an enhanced relationship and output between the science and business communities.

Scientific literacy for better decision making was raised as a primary outcome in a number of interviews. WA believed that 'once people have had some science training, if they are thinking about anything they do in their life, they say "gee, I wonder what the facts are" or "what do the authorities say about this"' resulting in critical thinking and decision making. Some such as AMA, the main proponent, made direct statements that a scientifically literate society is 'a society that is able to make informed decisions', adding that it is 'more able to make decisions about their own health and society wide issues like climate change on the basis of some understanding of what science is and what science isn't'. AMA emphasised the importance of scientific method as part of this understanding, with the aim that a SEA would be able to 'to interrogate information so as to better understand it and make better decisions'. As noted earlier as part of the discussion on pragmatic benefits, AMA's example of people better able to make choices about healthy or unhealthy eating also applies to the discussion here. IC shared this sentiment with his concise statement about the public that 'the more they are engaged with science the more likely they are able to make an informed choice…so the more they know the better their decisions will be'. GD's opinion was in line with this argument with his view that the public need to understand to safeguard themselves:

> they need to be aware that in the future they will be and indeed are citizens of a country where issues of science are very important. So they need to be able to understand enough science to know when they are being taken for a ride with you know dietary supplements or medication or particular shampoos that have formula X, so all of that stuff is I think kind of important.

GD added to this discussion that a scientifically engaged public is one that has 'a greater understanding of the sort of questions that science can answer, the sort of things science can't answer, you know what are the realms of faith and belief opposed to science and rational evidence'. Informed decision making is not just limited to the public. AMA felt the same for all sectors, stating that

> I think training and an ability to use the scientific evidence base is relevant in other sectors – whether you're a farmer, whether you're in the business community, whether you're in education, whether you're a public servant, whether you're running a small business, you have an opportunity to innovate and use best practice; and best practice is informed by the evidence base. So you have an opportunity to improve or put your best foot forward by being scientifically engaged.

WA shared AMA's view that all sectors can benefit from using scientific evidence. He stated that 'all major parts of our society – civil society, government, business – engage with science, but particularly with scientific evidence, in what they do'. WA did not purely raise the importance of public decision making, but instead his discussion focussed on being informed by 'independent scientific advisory bodies and scientists in their departments' in the decision making process by governments.

WA continued to emphasise the importance of scientific evidence not just in decision making but for the consumers of the information. He outlined the view that

> we want opinion leaders to do the same [verify claims with scientific evidence], so that journalists, radio broadcasters, magazine editors recognize how big a role science plays in society and feel that it is not just another view point – science is the way in which we get the evidence upon which we do build a good healthy, wealthy society, so that's a big a big wish.

This statement also raised the notion of the importance of information seeking behaviour, supported by another statement from WA, who outlined a desire for

> a community who feels that when they hear the latest thing that is good for your health they might think, "oh, I wonder if there is any evidence for that" and go to some reliable source such as the NHMRC or somewhere to check whether that's the case.

GD, IC and AMA shared this view in support of information seeking behaviour. GD outlined the aim 'where the public feel comfortable with science, they know who to approach if there are questions of science, they know who to trust, and indeed who not to trust', and as IC stated it, the 'ability for the community to make judgements when it has to'. AMA made a similar statement with the aim of

> a greater proportion of people...to have an ability to interrogate information…so for them to be able to sort out what is real versus what is good information, valuable information, what is evidence based information versus propaganda and other things is important.

As a consequence of this

> if more people are able to enquire, scrutinize, interrogate information they're engaged, they're totally engaged, they're practicing science in their every day world in many ways they're practicing the discipline of science.

AB offered a different view on the use of science. He did not comment on the practice of evidence based decision making and the use of science, instead discussing the ambiguities around the terminology used as part of the scientific enterprise. He remarked that 'to understand scientific knowledge isn't nearly as black and white' and that it is 'ambiguous in its outcomes'. He went on to discuss the fundamental differences in the terminology that scientists use and how this translates to the community and the potential for misleading the community. AB remarked, 'are we telling them in certain instances that science is absolute when it's not – and we are. …So that is misleading people, raising expectations and the community does that in a very damaging way all the time'. AB put forward the alternate view that science gets into trouble too as it is 'so couched in a probalistic language that the community at large has no idea what it means'. He argued that this confusion regarding the language of science is 'a real danger'.

Related to information seeking behaviour, AMA again emphasised the importance of the peer review process and in particular the role of universities. She stated that as part of the scientific process it is expected that scientists' 'conduct is rigorous and where application of that peer review process is not compromised in research activities undertaken by universities and in their teaching of students, and equally the student experience as well'. WA shared a related concern with respect to the fidelity or reliability of information, remarking, 'well there's clearly a need to try by some means to help people understand what's reliable evidence and what isn't'.

All interviewees highlighted the relationship between science and business, and the benefits of a strong connection between the two. GD discussed how these connections with research and development (R&D) can enhance business as he remarked that ‘companies don’t often have the R&D capability or need to have it, but they do need to be able to engage with smart people from time to time who can help them solve particular problems’. He went onto argue in support of the value of science for all businesses, not just R&D, as the ‘non science businesses still use science’. In support of this view, AB offered a different perspective, discussing at length the role of the ARC and his concern about ‘strengthening...that research-industry connection’, AB goes on to discuss

> how the knowledge that is developed within universities has application in the broad – the benefits of research, and there is an enormous international conversation about the articulation of the benefits of research and indeed the strengthening of that research industry connection is one of the things that I think this government is very keen to stimulate.

Others such as WA and AMA focussed more on future ideals in terms of the relationship between science and business. WA outlined a business community that

> would be using scientific research more than they do. They would be sponsoring scientific research, they would have stronger research and development activities, they would be employers of more people with scientific backgrounds, in appropriate jobs of course…so some leadership really.

AMA outlined a similar view but focussed on the integration of science into the business community as the latter ‘would have on their board, within their ranks, within their workforce people who have an understanding of science and are or will have potentially been practicing scientists…having scientific strategic advisers on their boards…that better their business decisions’.

Theme 3: policy, political decision making, investment and the economy

The importance of science in political decision making and the relationship between science, policy and political decision making was raised by the interviewees. There was a shared view that policy built on scientific evidence is a good thing, an ideal thing. IC put forward his opinion with the statement ‘I would prefer to see them [government] much more willing to build policy off a solid scientific base, wherever that’s appropriate, and it’s appropriate in many instances – maybe not all’. AMA shared a similar view as IC, retaining her strong views of evidence based policy, to build governments which are

> able to make decisions by taking into consideration amongst other things the scientific evidence base; and I say amongst other things because every government will make decisions based on many factors and that is appropriate and I respect that, and I understand that.

AMA went on to make note of the current environment in this respect and how

> at the very least, part of that decision making process - one important part at the very least - needs to be scientific input. I don't think that happens routinely at the moment, it happens sometimes. It is more routine for an economic factor to be considered rather than the scientific factor and that's unacceptable.

WA put forward his perspective on government decision making, sharing the same view as IC and AMA on the appropriateness of decision making by government and how they need to take into consideration often opposing needs. He stated that

> most governments talk about making the decision on the basis of evidence, which they mostly do, and sometimes they don't, and there often are very good reasons and we call it democracy. And so sometimes they get pushed by the weight of public opinion to do things where they may not be in pure scientific evidence based grounds but the most effective thing to do.

IC furthered this point about the competing external influences on government decision making, with the statement, 'I think too often they are inclined to understate the value of the evidence in order to get a subjective position adopted – subjective political decision'. He outlined that the ideal process for governments would be to 'look at the evidence, and listen to the evidence, and build policy on the basis of evidence'. WA reported on what occurs in practice in relation to some government decision making and the messages they send, particularly in times of pressure. He stated that

> there are times under pressure to do something, when there may not be evidence, that they at least set out what the evidence shows and respect that and mention it even if there are other good reasons to make a decision it might not be entirely in accordance with the evidence. There are good reasons, you see it all the time and you know it might be that following evidence directly might disadvantage an important part of society.

WA made note of the importance of communication as part of the decision making process.

Another area that is related to policy decision making that often involves the public as a key stakeholder is emergent technology decision making. GD raised this as an issue noting how the upstream engagement with the public is integral to these discussions about emergent technology. He stated how

> science is not just about generating wealth of course, it's about solving problems…so many issues of science that are better debated out in advance of the technology before it gets to the stage where it becomes a problem. So the engaged society would have opportunities for that dialogue, debate, there would be opportunities for industry and science to get together and discuss common areas.

Policy decision making is not the only focus for governments and science. As GD commented, 'governments can play a role in the regulation of science', and this can be seen in effect as 'the Federal Government will have certain high level mandates and responsibilities and they will be mirrored at a regional level by the state governments', noting the national coordination and flow-on effects of national decision making with respect to the regulation of science.

In addition to regulation, investment in science in Australia comes largely from the government. GD remarked on the role of the government, 'at one level it's to fund some of the institutions of science'. GD and CJ discussed at length the government's role in investment in science. CJ remarked that the current Federal Government 'is making an investment a little bit below the OECD', an opinion shared by GD who described how the government's role is 'to decide how much and what proportion of the GDP should be spent on scientific research and how'. In addition to proportions of spending both GD and CJ made note of the need for government to be strategic in their investments. CJ put forward the view that in the ideal we 'would have frankly more money to invest in science, you would have a more intelligent investment system so that there was a long-term strategic set of goals we are looking at'. Further to this point, GD outlined the need for governments 'to develop some research priorities in a small country like Australia - you can't expect to have excellence right across the board, so you have to identify areas of particular focus and that's where priorities can help'. He went on to discuss that not only do 'governments need to fund research infrastructure, they need to create an environment where industry can capitalise on the output of science. So, the turning of science and discovery into commercial opportunities' and encourage business and industry to participate in this, in turn enhancing the economy. AB put forward a different view. He reflected on the current funding environment and the government's strategy behind this, providing evidence that the strategic funding of science within Australia is already occurring. He stated that the government's 'significant spend by far is in that health space', and that this is largely a deliberate decision as 'one of the ways of ameliorating that impending cost of health is to more rapidly implement the scientific knowledge that's developing in that area'.

Strategic investment by government, like that outlined by AB, is closely related to economic return. Other interviewees made note of science as being of benefit for the economy, while CJ stated that in a SEA we 'would have an economy that was based in knowledge industries rather than, say, the mining industry'. She offered the view that 'science is the key to the future, it sounds clichéd but it really is' and that Australia should invest in science by getting 'the kids educated in this area and working in the economy, and frankly making money and raising the standard of living, and dealing with the extraordinary challenges we all face'. Within these statements CJ made note of the importance of science to the nation's economy and future and that 'without better engagement with the Australian community we will never get a scientifically engaged country and we will never get the sort of social and economic benefits everyone wants'. GD discussed the economy from a different perspective in terms of the cycle of spending between government, science and the economy. He described the aim of

> good engagement between the policy makers and the public and the media, and the scientific community, because that basically is how the research spending is justified, and that loop between economy and the scientific research establishment generates wealth for the country.

What is apparent from these interviews is the complex and interdependent relationship between science, policy, political decision making and the economy in which the government has a pivotal role.

Theme 4: networks and communities of science

All interviewees identified universities as having a leadership role, not only as creators of knowledge, but also as a vital part of the community: as GD stated, 'universities exist within their community'. He elaborated on this statement, explaining that universities

> have to be part of the community and therefore they have some corporate social responsibility, so they have responsibilities to be good citizens within that environment, to help inform, excite, inspire the community, as well as working within their discipline boundaries and relationships both nationally and internationally.

The responsibilities outlined by GD are vast, and were shared by WA. He discussed the research development and leadership role of universities in society, stating that

> I think universities are the main leaders, the main drivers in our society of engagement with science. They do most of the scientific research, they stand for evidence and rational discussion in society and they provide most of the facts, most of the evidence for the big debates in society. Whether they are social matters, environmental matters, or business matters, that they provide most of the energy there.

WA identified universities as a focal point of 'leadership in recognising that our future prosperity relies on research and science and being proactive for their own self interest'. WA was hard on his own sector, as he remarked 'well, we [universities] can always do better'. GD presented his view of universities and their position in society, with the statement that ‘relationships are important, so they [universities] are big employers with the community…in some towns and cities they’re the predominant part of the economy’.

Universities were identified by the interviewees as having both a leadership role and an economic role in society. WA and GD both raised concern over the initiatives that some institutions undertake typically for financial reasons and the perception this creates in the community. WA stated that

> there are some areas of fringe science that universities are a bit tempted to get into for financial reasons, such as chiropractic and some of the complementary medicines. I think they should think about that, because it does send a signal to the rest of society that, well “we are engaging so it must have value”, because universities are so associated with rationality in our society.

GD put forward a different perspective on the community leadership role of universities, stating how ‘some universities sponsor local events like the Brumbies [rugby union team] here in Canberra, the University of Canberra Brumbies’, noting the negative perceptions this can bring relating to the fundamental role of universities, and what they are funded to do, is education and research – not sponsorship and advertising. Yet, these sorts of initiatives also have an economic benefit to the local, in this case sporting, community.

Universities are not alone; they are part of what is considered a larger ‘ecosystem’ by WA. Others discussed the interconnectedness of science in society. Despite AB stating that ‘my focal point was the universities’ he made note that ‘there is a strong connection between universities and local and national government, and again I’m looking at the research activity in universities as this dimension’. GD discussed what he considers a virtuous cycle:

> so it becomes a virtuous cycle and everyone wins if you get it right. Because the community wins by having that higher level of engagement: it enriches their lives, empowers them to discuss things, understand things, to know how things work; and science community get, well, support - there’s a consequence of being well liked by the public, and the ministers, the politicians seeing that level of support coming through encourages them to fight for funds. And that’s where you get the virtuous cycle, and youngsters are encouraged and interested and excited and so they study and everything keeps going. If it doesn’t work it tends to spiral down into a lower level of activity.

Others shared a similar view of the interconnectedness of science. AB focussed on linking science and industry. He remarked, ‘if you had to think about how things are connected at the moment…how do you stimulate that connection a bit more? The connection between universities and business in particular, but also the business community in the broad’. CJ used the same terminology as GD in her statement describing the education sector as a ‘kind of virtuous cycle’. CJ went on to talk about general responsibilities as she put forward the view that ‘all these sectors have to work much more closely together for us to get a scientifically engaged Australia’. IC did not mention specific sectors instead put forward the broad view, as he stated ‘I think each [sector] has got a role to play consistent with its particular time, and where it’s engaged in the process, and how they will take and build a scientifically literate community’.

GD tended to be rather aspirational in his views on the ‘virtuous cycle of science’, as he stated

> I think all of those things come together – at the same time you’ve got the young people being inspired, motivated by, you know, school and informal learning environments, teachers being well supported and feeling empowered and inspired to teach, and I think all of that comes together to create the country we need.

The importance of leadership in science, and notably by universities, is not restricted to national leadership. Most interviewees made note of the global community of science and the need for international recognition. As AB described, ‘science as an activity is not a single national enterprise, it’s very much an international enterprise’. GD discussed the importance of international networks as

> science cannot be conducted in isolation these days…it’s important that the community these days doesn’t stop at the boundaries of the country we are now – we have global communities, and those online communities…can be anywhere in the world.

WA and AB were more pragmatic in their concerns about the nation’s international standing with respect to science. AB shared GD’s view, as he stated that ‘I think it’s important that Australian researchers are among the best in the world and deeply engaged in activities in the world, because without that Australia gets left behind very quickly on a whole lot of fronts’. WA also shared this opinion, stating the need for Australia to

> retain our membership of the leading countries of the world, the G20s, OECD, those places where we have to be recognised for the quality of our science and the quality of the use of science in public policy if we are to be regarded as a sophisticated advanced country.

GD offered a different perspective on the internationalisation of science in terms of co-investment by different countries in big infrastructure for science. He remarked on the value of ‘government to government relationships internationally, and that’s very, very important these days because science is global and a lot of science can only be done by co-investment from different countries’.

The interviewees' views on what a scientifically engaged Australia should look like in terms of networks and communities broadly identified universities as practitioners of science and as leaders in an interconnected and global community.

Summary of emergent themes for research question 1

Stemming from the discussion of research question 1 for this chapter of 'what would a SEA look like?', theme 1 identified the importance of science; whether it was idealistic or pragmatic motivations, all interviewees agreed that science is inherently important. The benefits of a SEA they identified included: increased scientific literacy in the public, the recruitment of more students into universities to study science, societal benefits from informed decision making and the adoption of emergent technology – particularly by the public, business and education sectors. A prominent theme that emerged from all interviews is the belief that the public requires education to improve their understanding of science, an opinion reminiscent of the PUS era. The primary, secondary and tertiary education sectors were all identified as being responsible, at least in part, for the publics' education, noting the primary role of universities as propagators of research. Theme 2 focussed on enhanced outcomes from improved scientific literacy, and that through this the public would make better decisions and exhibit better information seeking behaviour, and that all sectors would benefit from using scientific evidence as part of their decision making, resulting in an enhanced relationship and output between the science and business communities. The importance of science in policy and political decision making was the focus of theme 3, with the shared view that a SEA would be one that develops policy based on scientific evidence, acknowledging that the government does need to balance this against external influences and opposing needs. Interviewees discussed this complex and interdependent relationship noting that the government plays a pivotal role, particularly in the investment and regulation of science. In a SEA the government would strategically invest in science, with a focus on areas of economic return benefiting the economy. As part of this they would create an environment that enables industry to capitalise on the outputs of science, encouraging more commericalisation and innovation. Theme 4 discussed the complex relationship between the networks and communities of the different sectors, described as a 'virtuous cycle of interconnectedness'. However, universities in particular were identified as having the primary role in a SEA, not only as practitioners of science by also as national and international leaders.

Research Question 2: 'How do you Create a Scientifically Engaged Australia?

This section presents the emergent themes from the interviewees' responses that addressed the question 'how do you create a SEA?' As with research question 1, interviewees' responses did not agree and not all interviewees contributed to every theme. The first identified theme includes the mechanisms by which a SEA can be achieved at the individual or grassroots level with a focus on the audience or receiver: the discussion from the interviewees highlighted the importance of the communication of science, and the common mechanisms by which to do this including the significant impact of the internet on how we now communicate. This discussion identified teaching and learning and the ability to understand the evidence base as being integral to achieving the aims of a SEA. In addition, the influence and strength of the community featured in this discussion along with commentary on metrics commonly used to measure the impact of communication mechanisms.

The second theme discusses the mechanisms identified as contributing to the creation of a SEA at the institutional level, presenting commentary by the interviewees on the responsible sectors, and infrastructure support. This discussion highlighted the role of universities and governments as the primary drivers of the creation of an SEA. Investment in science, primarily by governments, was raised in this discussion and to a lesser degree the role of business in achieving the aims of a SEA. The responsibilities of the sectors were discussed, not all interviewees agreeing on who is ultimately responsible for achieving a SEA. However, some individuals and sectors were commonly identified as being primarily responsible.

Theme 1: individual mechanisms

There was consensus from the interviewees that the communication of science to the public in general is an important mechanism in creating a SEA. AMA remarked 'communication is absolutely the key'. AB showed his support of this view as he commented that 'the telling of stories that's a good thing'. Others like GD were more specific in their support of communication mechanisms, outlining 'informal learning, informal education sector – the science centres, the museums, the media, the publications, clubs - all of that's important to add richness, and depth and motivation' to the Australian public.

In addition to general support for communication, CJ emphasised the importance of good communication of science, using the example of a Prime Minister's Prizes in Science recipient, as a 'magnificent communicator that he made it really clear to everyone in the audience…what he does is incredibly important, unbelievably good fun and Australia's really, really good at it'.

CJ was the primary proponent of the argument in support of the importance of academics in communicating science. She went on to state the belief that 'it is no longer the case that an academic can beetle away in their lab and just keep going without talking to the public about it'. AB supported this view of increased participation of academics in communicating their science with the remark that 'the putting out there of researchers to tell their own stories and that's really, really important'. However, CJ cautioned that 'not everyone is going to be able to do this, some people just can't communicate clearly', a view shared by GD as he remarked that 'there are some scientists who under no circumstances should you allow anywhere near the public…some of the best scientists, brightest scientists, are horrible communicators and shouldn't be anywhere near the public…under any circumstances'.

CJ argued that further assistance is needed for academics to support them in the communication process. She noted that

> a certain amount of support internally in the university for helping people express, and you give them forums, and frankly sometimes you give them some credit for having done it - because it doesn't formally slot into the…promotion scheme at the moment.

AB's statement disagreed with CJ; when discussing the university promotions process he identified that

> there are [currently] three different dimensions that you get evaluated at, with an implicit expectation that you do want to be there interacting somehow in a positive way with other people, be it the community in the broad, or relationship with industry or government or whatever…[It is] seen as part and parcel of a well rounded academic, within the university environment.

CJ discussed at length that 'universities have a fundamentally profound role' and that it is 'incredibly important that universities work really hard to communicate the really important science they are doing', adding that they 'have a duty to do that…it should be part of their mission'. No other interviewee was such a strong advocate for the role of universities and in particular the responsibility of academics to communicate science. IC offered a different view on the duty of scientists, putting forward his concern that scientists need to become more involved in public debate and evidence based decision making, and noting that it is the responsibility of the scientist but 'partly about getting scientists engaged in public debate in a way that's accessible to scientists, early, consistently'. IC's comment also related to personal development opportunities for scientists as a mechanism to help create a SEA, as he focussed on elevating the profile and expertise of scientists and increasing their participation in society. Other interviewees shared this view of staff or personal development having a role in achieving a SEA. CJ's commentary was limited to assisting scientists to communicate through 'forums'.

AMA's comments were related to IC's: insofar as enhancing scientists' contribution, she asserted that the establishment of 'joint appointments would be useful' mechanisms to achieve this. AMA elaborated on this as she discussed that an ideal outcome would be to 'enable scientists to spend some time in different forums, so in news rooms, in the media, in parliamentary offices so they understand the reality and vice versa…to be able to cross fertilise ideas'. WA suggested a mechanism would formalise this exchange of ideas at the high management level, saying, 'it would be good if they had a "business leaders for science" forum or something like that'. GD offered a similar suggestion through the remark that 'businessmen [sic] tend to have little time, so what seems to work are those really sharply focussed business breakfasts'. GD extended his suggestion, proposing a similar set of mechanisms not aimed at high level management but rather the professional development of public servants, through 'short courses, breakfast briefings, general encouragement to get involved in science are all important ways you build capability'. GD was the most vocal interviewee in relation to staff development mechanisms within the business community. He put forward a variety of suggestions of how businesses 'could fund programs, they can support the development of their staff, support exchanges, they can travel, they can see other business opportunities with other research bodies'. In addition to these communication mechanisms GD raised the notion of the need to 'build mechanisms to exchange information particularly in government…and a bit of coordination'. CJ offered a different view on the role of the business sector in communicating science. She raised the belief that not all communication is altruistic, much is motivated by self interest. CJ cautioned that 'you need to think carefully about the fact that business is really different to universities and their major driver is making money…so when you see an ad for scientists working at Chevron you need to keep it very clearly in your head that it is an ad for Chevron'.

Throughout their discussions the interviewees suggested a myriad of potential communication mechanisms. AB offered a narrative on current science communication practices from the perspective of universities, remarking that

> if you look at the connection between universities and the Australian community there are lots of outreach activities done in every single institution in the country of various sorts, public lecture type things but also more deeply embedded in getting the community engaged with what's happening in research and similarly to the educational sector.

AB's narrative contrasts to GD's, who provided what can only be described as a comprehensive shopping list of suggested communication mechanisms. He reported that 'university outreach activities, talks, lectures, programs, open days, I think are all valuable mechanisms' and then went on to expand the list with 'national science week is a good example of a high profile short term event…national tours, national experiments', and later mentioned the 'need [for] deeper opportunities to engage with science and scientists, and that could be through extramural courses, talks in universities, outreach programs, it could be through magazines, journals, media'. In addition, GD discussed at length the role of the 'informal education sector' of science centres, museums, and the media.

Many interviewees mentioned the media as a mechanism for communication, but only IC and GD provided any additional commentary on its present use. IC's critique was pragmatic with the remark that 'the pressure is on the media to give equal airtime to anybody with a view'. GD provided an aspirational view about the need to 'build capability of science in the media that facilitates an exchange', and later remarked in the same pragmatic fashion as IC that

> part of the problem comes of course when the media get involved, then they always look at…balanced reporting, and it's kind of hard to get that balance right. Often they sell a controversy where…you often end up with the fringe element having the discussion rather than any moderated sensible rational discussion.

The internet was identified by all interviewees as a key mechanism for science communication. Some were more cautious or guarded in their support, but others like GD offered direct and even enthusiastic support: 'I think the online stuff is going well, and I don't think there is anything that anyone can do or needs to do particularly'. IC offered a different view with his comment in relation to the prolific use of the internet, cautioning that

> scientists have got to be aware of the fact that people's ability to get information has changed, and then people's ability to pass an opinion has changed. So social media gives everybody a view – they don't even have to own it, they can put a false name on [it]…I think that's pretty weak.

The broad consensus was that the internet has revolutionised how we communicate. CJ remarked, 'so kids now spend hours and hours Facebooking, tweeting or Instagramming or whatever you know model it is that they use…the technology, the technology is an absolute game changer'. Some such as AMA claimed that it is useful tool, with her comment, 'Google can actually provide some reliable information. Don't get me wrong – I am not suggesting Wikipedia as evidence based policy. But, it is a starting point to understand something that's difficult'. Others like AB argued that it allows the public to be in control of the type of information they receive, because the 'community can switch on and engage in some very rich and deep senses in the discourse around research activities/scientific activities' through various websites. GD furthered this sentiment, stating that it creates 'plenty of opportunities', and making note of the use of the internet in student education and how 'learning is now 24/7 for young people, they expect to be able to learn any time they want to, in their own way, using their own devices…using online resources and tools'.

The interviewees identified the internet as the primary mechanism for science communication and it featured heavily in discussion about information seeking behaviour. For some this was implied. Others, such as AMA, explicitly reported on the default use of the internet as an information seeking tool, in this case by professionals. She described the actions of the attendees at a recent conference called 'Science Meets Policy Makers' when they were asked for a show of hands 'if Google was their first port of call when they had to report to a ministerial request, and at least 70 per cent of the hands went up'. The ability for the public to find adequate and trustworthy information on the internet was a common theme amongst many interviewees. In discussing the public's information seeking behaviour, WA commented that 'there are reliable places to go for information. It's just they [the public] tend to get lost in all the other voices, many which have a commercial interest'. He elaborated further, raising concern that it can be hard for the public to know what websites to trust, recommending that 'usually something that has a dot gov…or something I think people do feel like they can trust a bit more'. GD shared WA's concerns about reliable information on the internet, stating how 'there should be a central site where you know people could go and find out all the information that is government science and things like that'.

Further to finding information, concern was raised by WA and AMA on the ability to understand information found on the internet. Again, WA was the primary proponent regarding the public's ability to adequately distil the information, and the need for reliable sources of information, stating, 'I can't over-emphasise that people need to know where they can go, other than Doctor Google, for reliable advice'. He argued that

> people can't be engaged if there is nowhere to go to get reliable information, and it is one of the reasons why, for example, we and other medical research bodies around the world are pushing the open access issue.

AMA made a similar comment as the primary advocate for a centralised database, not focussed on the public but rather the public service and in particular their actions in seeking advice for government. She proposed a mechanism similar to ones used in the UK: 'a sort of database is produced by Chief Scientists in every department…by the equivalent of the Parliamentary Office for Science and Technology in the UK'.

Related to understanding, the fidelity of the information was a key feature raised by interviewees. WA raised his concern that 'there's clearly a need to try by some means to help people understand what's reliable evidence and what isn't'. Others including GD and AMA shared this concern, as noted in their comments with respect to the creation of centralised websites that provide reliable information. IC offered a different perspective on the fidelity of information on the internet. He cautioned the use of the internet and in particular the longevity of information, stating how

> [if] you just go back into the internet you can find things that are done 15-20 years ago that were shown to be wrong soon afterwards but they've got a continuing life. Whereas, in the old days they'd be published somewhere and then they'd sit on a library shelf unless someone discovered them. But now you can Google vaccination and autism and you would find a paper that said there was a link, but shortly after it was published it was shown to be fraudulent and that the person was disbarred.

He expanded on this argument, stating, 'unless you do the extra work to see what has happened as a consequence of that paper, you can just go back to that paper and say "here is the evidence, everybody's ignoring it"'. This view on the importance of the public's information seeking behaviour was also shared by AMA throughout her interview as she reiterated that the need for the public to have the 'ability to interrogate information' and to 'make better decisions is really important'.

In their broad support for the use of the internet, the interviewees made note of the vast opportunities and new methods that the internet as a communication mechanism provides. AB commented that the 'various websites that exist to tap into…to give people information around [diseases] is an instance of perhaps a good way of doing it'. He went on to caution that not all areas of science can be communicated as easily as others through websites, stating, 'it doesn't always work with quantum science or something like that'. GD shared his support, stating there are 'plenty of opportunities for individual scientists to attract followers and actually engage with a micro community of interest in a particular topic' and furthermore that mechanisms are used 'increasingly through the web where, you know, with blogs and websites and other social media'**.** AMA also discussed the role of social media, praising it as a mechanism for science communication, with a personal reflection:

> it wasn't until Twitter that I would routinely read the editorial in *Scientific American* because the editor was a mad tweeter and she'd always post it and make it look really interesting, and so I would read that and therefore the breadth of what I read and the depth of what I read increased.

CJ offered a different perspective to Twitter in her remark that 'it is quite challenging as it 'makes you think really, really clearly what it is you're going to say because you know everyone is going to have a view in 30 seconds'. WA's support was not as direct as AMA's. Instead he discussed how technology and in particular smart phones have changed the way the public spend their time, remarking on the vast number of smartphones used by Australians and that

> most people engaged more with their mobile phone than anything else so I can't tell you how to make people more engaged in science than their mobile phone, except for a reminder every now and again – "do you know 7000 pieces of research contributed to this phone" – or something.

Another use of the internet and to a degree social media was raised by WA (and shared by CJ) in his support of online media, in particular that he is a is 'really a great admirer of this thing called *The Conversation* which is tapped into the skills in our universities and is a very good strong voice about evidence and research'. CJ made note of crowd sourced fundraising as another mechanism made easier through the use of the internet. She stated that for 'crowd source research funding…the technology means that it is not labour intensive, so the technology can reach a broad number of people quickly'.

The notion of citizen science and the opportunities that it creates is one specific mechanism that is enabled by the prolific use of the internet. AB made note of this in his statement that 'it is interesting to see how [the internet] is developing and technology is enabling people to participate in things'. GD added to this discussion with his belief that 'there's opportunities for broader engagement of the public and the informed amateur with science and that's where citizen science is emerging', and that it is the internet as a tool that

> enable[s] more people to engage and you…there is what's been described as a cognitive surplus - there are a lot of smart people around with time on their hands, and an ageing population of people who you know generally are interested in stuff, and so I think the area of citizen science is an interesting one.

GD went on: 'its not to say that it will replace real research…but I think there will be genuine projects where the public at large can make a much greater contribution to gathering data and analysing data'. AB also discussed the opportunities that citizen science allows, offering the view of the direct societal benefits that it brings, making note of 'how NASA is looking for comets that may come our way or space objects that may come our way doing citizen science'. GD contextualised the efforts of citizen science activities in terms of science communication outcomes, stating that 'the best way to get engaged with science is to do science, and the more people that we can get doing science I think the greater the level of science engagement will be'. CJ offered an alternative view on citizen science, saying it is a

> pretty good example [of engagement, but]…I know there are divided views in the science communication community about citizen science... but citizen science at its best is a real scientist grabbing a whole bunch of people in the community and getting them really engaged about a project and getting the fantastic volunteer workforce and those 20 or 30 people then become unbelievably engaged in in the process.

A further example of the internet providing opportunities for new methods of communication can be found in the recent surge in Massive Open Online Courses (MOOCs). AB reflected that

> MOOCs are going to be a disruptive technology and will supplant the further education path. They will actually sit out there and be accessible and people in the community that might have done a further education course won't do that they'll actually go and do a MOOC and be satisfied with that…and that's going to be an interesting thing to watch over the next few years.

Education as a primary mechanism to achieve a SEA was raised by all interviewees. WA was a primary advocate for the benefits of education with the statement, 'at the end of the day education is everything'. CJ shared a similar view with the remark that 'education is one of the key mechanisms right now from the bottom of school to the top of university'. GD provided reasoning in support of education, as he stated the belief that education would 'help develop the broad community capability and enough brain power to run the country'. WA provided a different perspective in support of education from the point of view of the recipient, remarking how children 'are interested in different things, and different things motivate them from early [primary] to late high school and beyond. …So, I do think it is really important; but the tactics need to be informed by an education expert'.

A common theme raised by the interviewees was the importance of quality teaching and the impact that teachers can have on their students. Some such as CJ and AMA provided direct statements of support. AMA discussed the ideal as 'having qualified teachers teaching subject matter', and CJ added to this point with her statement that 'I think improving the standard of education and science education…is really important'. GD remarked that 'teachers are the key' and went onto elaborate on how others have a role in quality teaching as

> teachers need resources, they need decent curriculum, they need flexibility to teach, and they need support, they need opportunities to engage with scientists, get scientists in the classroom, to get the students engaging in the research facilities…all those things can help.

GD added to his discussion by commenting on how business can enhance their role in creating a SEA by 'support[ing] teachers, or they can have open days or develop educational resources'. AB provided an alternative pragmatic perspective on teacher education, raising concern over the quality of teaching in terms of providing students with appropriate education outcomes to allow them to continue on and be successful in further tertiary studies in the sciences. He stated that

> again this is about pipelining, it's making sure that students who come through the secondary space are sufficiently equipped to embark on further learning that involves scientific knowledge. So the classic instance of this, do they have appropriate mathematics for instance…there are strong arguments that the training in mathematics has gone down…and if you don't train in the mathematics space a lot of the physical sciences space is completely locked out, so physics and engineering is completely locked out for students.

CJ made a similar statement relating to the opportunities for further study with her statement that 'if you don't do it right at the start you are going to have no one going to university and doing science'. Unlike his peers, WA felt as if he couldn't comment on the quality of current education, yet offered the opinion

> I suspect there is a problem in primary school, just in terms of the training of primary school teachers with very few having had a Bachelor of Science or other scientific degree, but I don't know for sure if this is a crucial problem.

WA's comments differed from others in that he did not discuss the quality of teachers instead focussing on their ability to inspire and motivate. He went on to remark that 'we all remember our great teachers and got enthusiastic because they were enthusiastic about something'.

Others shared WA's support of the importance of inspiring and enthusing young people. CJ emphasised the importance of early action, advocating 'engaging them [children] from the very start and importantly keeping them engaged. Something terrible happens toward the end of primary school and the start of high school where science becomes really, really boring'. WA provided further comment on this issue in discussing the Prime Minister's prize winners in science education. He commented that they are so successful because

> they've really have woven science, and science understanding and understanding of the layers of science, into their educational offerings that connect with real life and engage the curiosity and don't dumb down things but engage, engage with kids…make it interesting…its about engaging the imagination and enthusiasm of students.

CJ provided further commentary on the role of early intervention through positive education that will then be carried through the years, with the proposal:

> if you just start from the bottom up. I mean kids really like science, they don't even know it is science when they start doing it. Use my smallest kid as an example – she is in kinder, she is doing exciting things with balloons and static electricity and they do a bug collection at the local wetlands and stuff, so absolutely critical.

GD put forward an alternative method to inspiring students through education, remarking that he is

> a great believer in the idea of flip teaching where the students learn the knowledge part of the curriculum at their own pace using online resources and tools that can assess their progress. And in the school, contact hours are spent on more productive, collaborative, projects involving problem solving, teamwork, really getting that rich development of science and actually doing real science, and I think the opportunities exist these days to do that.

An understanding of the scientific process, or the use of the evidence base and the ability to interrogate information, were identified as key outcomes of quality education by IC, AB and AMA. Both AB and AMA made note that the scientific process is not restricted to the discipline of science. AB remarked, 'enquiry based learning – I think that's the vehicle for science, now it's not exclusive for science but it's very much a vehicle for science'. AMA added to this argument in her discussion about how these skills of enquiry are of benefit for all and again extend past pure scientific enquiry, through her statement that

> there is an evidence base there and there is an ability to interrogate whatever information you might have in front of you on whatever subject matter - that doesn't have to be scientific - that gives you the ability to inquire, to reason. That's really important.

IC also discussed the importance of understanding the scientific process and enquiry. But unlike his peers, he remarked that it is 'universities [that] have probably got to educate more relevantly, so not only are you studying a discipline but you're studying a process', and that by understanding the process you do not necessarily need a job in the discipline, but you have fundamental skills and understanding and a 'formidable process sitting behind them'.

Many interviewees returned to the notion of a virtuous cycle and the relationship between different sectors: as WA put it 'everybody has a role but they're all different roles I think' in discussing the mechanisms for achieving a SEA, where education was a key focus of this cycle. He stated:

> at the end of the day education is everything, and if we take a long term view of this the more people we have that have been through good schooling that understands how science is done, how evidence is accumulated, what is needed for science to be done, money, then you know you gradually change the conversation in the community.

Here WA identified education as the primary trigger in improving the public's relationship with science. CJ's reflections on education add to this argument in her statement that

> I think improving the standard of teacher education is really important, this is all a great big fat circle really. Because, you know, if you get the kids really keen at the start, you've got to have the teachers. So again I hate to harp back to the American examples, but training a hundred thousand teachers if you want more graduates – you've got to have more teachers.

GD offered a different perspective on the cycle of education. He made note of the importance of the broader community and sectors within the community in delivering education, as 'learning is 24/7 for young people' and as 'classrooms alone cannot deliver everything that's needed. So the school sector has to work with the broader community and the community institutions to support learning'. Unlike his peers, AB's reference to the cycle of education was restricted to a pragmatic statement that 'universities are very aware about connections to the education sector particularly into the secondary space. Some of it's, a lot of it is primarily self interest – it's about pipelining'.

Like the education sector, the community has a unique role in that they are often seen as the receivers by science communicators. This view was supported by CJ's statement that 'the area that they [all sectors – government, business, universities, and education sectors] have to interact with the most, and the most profoundly, and where the biggest failure is now, is interacting with the Australian community'. However, the discussion presented by the interviewees highlighted that the community also have an essential role in achieving a SEA. AB discussed how 'people are wanting to get engaged in a positive way' and that 'if you can get the community to do something, and they are engaged and wanting to do that, that's really good and exciting for people'. He gave Landcare initiatives as a positive example of this. GD provided an alternate view on the importance of the community and how 'good companies bring the community with them, rather than end up trying to fight the community', a pragmatic take on managing the relationship with the community highlighting the influence an unsupportive public can have.

All interviewees made reference to the relationship between the public and the health sector, highlighting the view that active participation by the community in the communication of science is most common in the health domain. WA provided perspective through his statement that

> there are so many community based charities in patient support groups, patient advocacy groups, charities that fund a little bit of research in particular areas…last I heard there were 200 in cancer alone in New South Wales alone.

He believes that there is a huge movement at the community level in heath because 'everyone's into their own health'. WA and CJ were the main proponents of this argument. WA discussed how a proactive community group can be of broader benefit to the Australian community, as

> for all our [NHMRC's] evidence based statements, they [the community interest group] grab them and send them around to their millions of members, because they know patients actually want to know what works and they want patients to know what works.

CJ's adds to this view as she commented that 'the fact that people basically trust other people who are really similar to them'. She went on to remark that 'the people who have the most influence in convincing mothers - and usually it's mothers - to immunize their children, are other mothers with children' and that it is 'groups inside the community that represent' the spokespeople and networks that can be so influential. WA also made note of the effect of the community rather than education on levels of immunisation, stating

> there's a very nice piece of research done about vaccination again. This is really a science issue. Science absolutely 100 per cent supports vaccination but there is a big anti-science, big anti-vaccination movement based on rumour and weirdness. And turns out the richer you are the less likely you are to vaccinate your kids, so it's not to do with education or access or anything else. The research has been a beautiful piece of research used by the World Health Organisation. Work done by a researcher of Sydney University shows that it's about norms - so the most effective persons are the nurses that see the mothers in the hospital or at the child care facility. Because if they just make this a normal part of life, they convince them that it's of value - that it's just a normal part of having a kid in our sort of society and mothers trust them. Whereas lecturing from the NHMRC or some other body - if people don't want to hear the story they're not going to hear it, they'll go to the anti-vaccination side.

WA provided an alternative view on the influence of the community in discussing how information is shared within the community, not through common interest groups but through networks, personal connections such as family and friends, or 'a bunch of their contacts'. He gave the example of when 'Dad says climate change is a "hoax to get people more research grants" which a relative of mine said, then some eight year old or 14 year old can go "oh, alright. Well did you know the following blah blah blah blah. Now do you think it's all a hoax?"'. WA offered a further example of the power and influence the community can have through a success story of an active community, 'for example when there were rumoured cuts to the NHMRC they publically advocated and went and lobbied the government, and they were more powerful than scientists going I can tell you'. CJ shared a similar story to WA, on the topic of technology as a 'game changer' for communication. CJ gave the example of how

> you can genuinely crowd source money these days, and you really can. I think in Australia we have only just had our really, really significant massive crowd source for a scientific project…two days after the government took power they disbanded that [Climate Commission] body and within three weeks they [the former Climate Commission] raised over one million dollars, I mean really, and that was a crowd source, so that is just going to the community, it is a really good example of engaging with the community.

CJ not only highlights what technology can enable, but the influence that the public, in this example by crowd sourcing funding, can have in bringing something about that they believe is of value.

The common presumption of a homogenous public was mentioned briefly by two interviewees. CJ captured it in her statement that 'I think it is a shame to lump the Australian community into one great big bunch'. GD made reference to it in terms of the existence of many 'micro communities' with interests in particular topics.

CJ, AMA and AB raised metrics and evaluation of activities as a mechanism useful for achieving a SEA, however each offered a different perspective. CJ raised concern that surveys of the public's scientific knowledge are not helpful: she noted her 'concerns about the sort of polling about scientific smarts that we do, I think sometimes all that ends up doing is humiliating people who don't know the answers to questions'. AMA's opinions agreed with CJ as she stated that 'I don't think it is important that we get an entire 24 million people in Australia…set some false target', adding, 'what we are measuring at the moment might not actually reflect practice'. AB offered a different perspective to metrics and how they do 'provide some very, very positive feedback to reward behaviours that we think are really important'. Unlike his colleagues, AB's reflection was not focussed on the public and their relationship with science, but rather was based on earlier studies of the evaluation of the quality of research outputs, such as publications, ahead of volume, namely the Excellence in Research for Australia (ERA) initiative by the ARC (Australian Research Council, 2014c). AB entertained the idea of 'an evaluations exercise that looked at the effectiveness of partnering relationships in the same sort of way could reinforce positive behaviours'. He did not see the model limited to interactions between the public and science, but primarily for enhancing the relationship between science, business and industry. He made note of the difficulties present in with feedback and evaluation in that the results 'do tell good stories and that information is a good positive thing, it doesn't give you the right sort of information for feedback to improving the process in a very direct sense'.

Summary of theme 1

The communication of science in general to the public is an important mechanism in creating a SEA according to all interviewees. Universities and scientists were identified as having a key role in achieving this, and increased participation by academics was seen as important and considered both a professional development opportunity, and as part of their statement of duties rewarded by promotion. Business leaders and public servants were also identified as having a role in creating a SEA through targeted activities such as business briefings and professional development initiatives. A broad set of potential communication mechanisms were identified, but the key mechanisms included the traditional media, the internet, social media, blogs and the development of a centralised government information database. The notion of citizen science activities as a mechanism was raised in conjunction with the prolific use of the internet in modern Australian society. Concerns over the fidelity of available scientific information was raised, in particular on the internet, as was publics' ability to adequately interrogate information – the latter being raised again as a key feature of a SEA. Education was identified as a primary mechanism, in particular the importance of quality teaching and the impact that teachers have on their students and their ability to enthuse and motivate. The interviewees again highlighted the complex relationship between the different sectors, going onto discuss the role of the community its ability to influence government decision making, and even their peers through specific spokespeople in the form of influential community leaders. Some interviewees raised metrics and evaluation of activities as having a useful role as a mechanism in creating a SEA, yet cautioned against setting ambiguous targets and objected to the PUS-type surveys of the public's scientific literacy.

Theme 2: institutional mechanisms

The general consensus from all interviewees was that the mediums by which a SEA is to be achieved are primarily focussed around universities and government. However not all the interviewees agreed on the relative responsibilities of each sector.

Universities were unanimously identified as having a unique role in the creation of a SEA. As CJ put it, 'universities have a fundamentally profound role'. The interviewees identified universities as central to all relationships with science as they are the main prosecutors of scientific research. CJ was the main proponent of the argument, stating, 'universities have a special responsibility because we expect them to be academically entirely independent, intellectually entirely independent'.

Opinions about the responsibilities of universities and scientists varied among the interviewees. CJ remarked that 'the responsibility is the biggest and heaviest and the liberty is the biggest for them [universities], so they get all the duty and responsibility'. AMA shared this view with her statement, in relation to their role in encouraging other sectors to participate in creating a SEA, shared that 'if the science sector were able to - and I realise what I am saying gives them a lot more responsibility than anyone else'. WA identified universities as the central medium, proclaiming that 'you know here [universities] is where things are generated and so that's the kind of base really', qualifying what he meant through the remark, 'not just universities but CSIRO and other public sector bodies and so on and some private sector ones'. CJ also made note of CSIRO and other government research institutions. Differing from WA's comments, she reflected on how 'everything I said about universities also applies to CSIRO and…other publically funded research institutes. Some of them are slightly more constrained…like CSIRO cannot talk about government policy', and how the responsibilities they bear are not as great as universities as 'many of them are inside the bureaucracy so they can't communicate in quite the completely free way'. GD also commented on the responsibility of research institutions as he identified that 'heads of all the agencies' are responsible for achieving a SEA and , going on to state that ‘these days no research agency can exist without having a focus on the public, and a focus on communication, and a focus on telling their story, of why they exist and what they do, and why they’re worth supporting’. AB offered a different opinion. Relating the role and broad responsibilities focussed on universities to the ‘ownership of science’, he stated that

> because the universities own [science], we [the ARC] give a lot of resources to universities both through direct grants research, but also universities are funded to train people, but as part of that there’s also enabling research. I think they have some responsibility for pushing out in various directions, and most universities I think would acknowledge that.

In addition to community responsibility, the interviewees asserted that universities and in particular scientists have a communication responsibility. CJ said that universities have a ‘duty to communicate what they are doing and they have a duty to communicate what they are doing better’. AB offered a similar perspective with his remark that ‘I think universities themselves would acknowledge that they have a responsibility to do this [communicate outside of the institution] and prosecute that’. Unlike his colleagues, IC put forward a strong view commenting on the role of universities in modern society, stating, ‘I think universities have tended to, have become things that are basically much more interested in the immediate’. He went on to outline a role for universities in the political environment, one where ‘universities have got to actually play a statesman-like [sic] role in this - so that means the professors, that means the Vice-Chancellors’.

The responsibility of universities is only part of the solution according to the participants. Scientists themselves also have a role to play, as AB made note of the need for the ‘putting out there of researchers to tell their own stories’. CJ put forward her perspective with the comment that

> I spend an awful lot of time talking about the importance of scientists lifting their game and doing a better job. That doesn't mean…that scientists carry all the weight on their shoulders. But if scientists don't take some responsibility for communicating as clearly as they can what they are doing and why it is important then you can't expect someone else to do it for you.

CJ again was the most vocal on this topic as she argued that ‘universities, scientists, need to make what we do more accessible, and that doesn’t mean we have to explain every single detail, but just make it more accessible so that the Australian community can come into the equation’. She went on to justify her statement, identifying a desired outcome ‘that kids that might not be considering a career in science might start considering a career in science’. IC shared this opinion, albeit briefer, as he remarked that ‘scientists have the responsibility of being much more actively engaged at all levels’. Unlike his colleagues, IC discussed at length the role of scientists in political debate, making note of the importance of ‘getting scientists engaged in scientific debate in a way that's accessible to non-scientists, early, constantly'. He went on to discuss the complex relationship between science and government, in particular political debate and decision making, identifying how 'scientists particularly I think have responsibility to get the evidence out there, political leaders have a responsibility to use it, and not to distort it according to some ideological position'.

Government was identified as having a profound role in achieving a SEA by the interviewees, primarily due to its leadership capacity. IC framed this discussion with his statement 'I think government's got a key role, because if government doesn't show leadership then the country has no leadership'. CJ shared this opinion, stating, 'government has an extremely important leadership role', and shared the concern regarding leadership by going on to say, 'their job is to lay out a really clear vision for what sort of country we can be' and that 'all the visions for what sort of country we can be include science absolutely from the start of the vision to the end of the vision'. Further to this point, GD discussed that

> I think it is the role for government, is that leadership and direction and encouragement of "this is important let's all try and do our bit". And it's a matter of putting together all the little bits of effort, little bits of money, to try and get a bigger impact and I think that's the role of leadership.

WA's commentary on this subject discussed at length the influence governments have, 'how powerful a voice of a leader can be', and the importance of symbolism by governments to the community. He described the (then) present political environment, where at the change of the Federal Government in September 2013

> the scientific community is a bit worried about the new government. Although science is still there in all the portfolios, nothing changed, not having a Minister of Science just sent an unintended, completely unintended, but nevertheless a message to the general community that science was slightly less valued than before.

He went onto remark how 'these symbolic things are terribly important'. WA added that there is a need for 'leadership by Prime Ministers, Premiers, Business Council Australia, [and] consumer health forums [and it] is really important', but 'you are never going to get away from…a million voices saying a million things' in terms of differing opinions and interest groups that feed into every political debate. He went on to add that, for science, part of this is 'making sure you have all the advisory mechanisms in place' for an ideal and effective political debate. IC put forward a similar opinion, focusing on the role of scientists in this process as he stated

> with respect to government I think it's the same - they've [scientists] just got to be constantly reminding government of whether scientific evidence is taking whatever issue it is and pressing to have that taken into account when it gets turned into policy.

Evidence based decision making by governments was identified by most interviewees as an ideal outcome of an SEA, yet few shared the same detailed view. WA noted the importance for governments to be 'looking for evidence'. GD raised concern over the level of scientific understanding in governments as he discussed how 'some government MPs have a degree in science but sadly not many. It would be better I think if we had more scientists in politics but sadly we end up getting lawyers and such'. He went on to state the belief that 'it's important to have that background in science', when discussing professionals in government positions. Others such as AMA and WA made note of mechanisms to ensure scientific advice is fed into the process. AMA remarked that it 'would be very useful…to have scientific advisers in every government department whose role is to make sure advice is provided based on the evidence base and not on a Google search - that would be useful'. Related to this and WA's earlier comments on leadership, WA discussed that when governments 'set up an expert working group to give' advice it is 'a really strong signal that this stuff is important'. Even GD shared in this view, stating in terms of action, that 'briefing MPs, keeping them informed' is a mechanism that should be put into practice to enhance evidence based decision making.

AMA continued this discussion throughout her interview, as the main proponent of evidence based decision making for all, not just governments. She focussed on how governments should be behaving, proposing an ideal situation where they would have 'access to people who are able to understand and interrogate the science and understand public policy in house or systematically available to government'. She went on to relate this to her earlier notion of the establishment of a centralised library that has the capability of providing briefs on request. The creation of this library would be in response to what AMA frequently witnessed as a deficiency in process, thus mitigating the need for advisers having to 'make 14 connections with academics in 14 universities or three universities and try and understand what the methodological differences between the two studies were – they don't have the time, inclination or even the knowledge base to do that mostly'. IC put forward a different view on evidence based decision making, putting the responsibility back on the scientists. He discussed that while political leaders are responsible for the use of scientific evidence in their decision making, 'it's up to scientists to keep relentlessly pushing forward the evidence that they've got and how it gets stronger or weaker or whatever with the passage of time'. CJ shared this view of joint responsibility as she summarised her argument on who is responsible, with the statement

> but I think it is a joint responsibility, I think government needs to lift its game significantly both in terms of the rhetoric and outlining the vision but also…resourcing the sector in a strategic, in a more strategic long-term way, laying out a vision and working out how you fund it.

In contrast to CJ's views, AB focussed on the role of funding agencies as government agencies, specifically his own organisation, the ARC:

> I do see one of the roles of the funding agencies is to be advocates too for researchers, quite a fine line that we walk because we are a government agency. But we are a government agency that has a mission to produce the best research in Australia – for Australians.

AB highlighted the complex and interdependent relationship between government and government agencies, universities and research institutions, and science. He went on to state that 'I do see that the funding agencies have a particular responsibility', adding, 'so there's a bit of, if you like, government engagement responsibility'. This contrasts with CJ, who was direct in her assertions over the role of government in creating a SEA, stating that 'I think government has an extraordinarily important role to play, and then they need to fund it a bit better'.

The investment in science featured as a motivator of action. Most interviewees made note of the implied link between investment and output. Elaborating on this point CJ made the statement that to 'invest on a government level' would mean that 'everything is flourishing and people want to do it'. WA put forward a similar view with the reflection that 'you don't get a more scientific literate community and business community unless you keep funding the science actually, and training the scientists, and training everybody in science, so gee that's another ecosystem'. AB reflected on a present problem in Australia of 'how do you stimulate the engagement between universities and the business community?…How do you strengthen it [the connections in industry], how do you make it stronger?' One solution he put forward to this 'is to quarantine resource and to make it specifically available to our researchers in university where they interact. So there's a mechanism…and that's somewhat successful'. Further to this, AB made a similar point specifically in relation to the increase in activity and outputs in medical research in Australia, in comparison to other areas of science and research, 'because there's money in the system to facilitate that'.

AB was generally more pragmatic in his commentary and vocal on this topic than his peers. He made note of a successful 'vehicle for stimulating the outputs [greater interactions between sectors, is to] put some cash on the table…except it doesn't fix everything so that's one of the problems'. He went on to note that other mechanisms to stimulate interactions between sectors do exist, and that increased financial support is not the only option, with the view that 'giving money is one, doing a proper evaluation is another one'. AB elaborated on this point, stating that governments 'are still responsible through people like us [funding agencies]…as a way of monitoring whether investment of the government has been wisely spent, and I would argue that it is, of course'. In addition to monitoring spending, AB discussed other means of government control and how 'government has at its disposal regulatory control, and insistence upon things', with the added remark that 'this government probably wouldn't like to use it in that way because it's strongly committed to a "reduction of red tape" strategy'.

Unlike his peers, AB posed the question,

> does the government have to do any more? And the government would probably rightly argue they give a truck load of money already to people to prosecute research, that probably is enough arguably from them. And there is a good deal of truth to that.

In contrast, CJ raised the issue of government investment in science, stating that

> we're not a really big country, we haven't got enough money for absolutely everything, so in many cases some quite difficult decisions will have to be made about what gets funded and what doesn't. But actually engaging in this properly, you know laying out a vision and then working out how you fund it and explaining to the Australian public clearly and consistently and over a long period of time - why it is you are doing what you are doing, and bringing them with you, rather than deciding science is fun one week and the forgetting about it next week. And you know funding something for a couple of years and then just dropping the funding off, which is - well, I mean, any Australian understands that is stupid.

The interviewees identified business as currently having a minor role in creating a SEA. Some discussed how businesses need to become more proactive in their relationship, and as IC put it, 'stand up to be counted and just accept the fact that most of them wouldn't exist if it were not for science'. CJ shared this view as she remarked 'business and industry are incredibly important and we are not doing a good enough job there, there has to be a better connection'. WA acknowledged that at present 'I think that's harder here [in the business sector]' to take a leadership role. CJ suggested improvements in the present situation, outlining the desire to 'create an environment in which universities and business can work more constructively together, and you create some incentives that makes it a bit awkward for them not to', highlighting again how universities have a greater responsibility than other sectors. CJ offered a different perspective to this discussion as to the role of business, as she remarked that

> I don't think their [businesses] responsibility is quite the same as in the publically funded institutions, and I think, if you think the business community will always operate in the public good, I think that is a very bad mistake.

CJ captured the sentiment in her statement, ‘I don’t think that you can expect that they will play this sort of goody-two-shoes science communication role that you might hope universities play’. AMA presented a different point of view with her statement that in the ideal situation, the business community would have a ‘good understanding of the scientific process and the importance of the evidence base and create good networks and knowledge to inform business decisions and innovation’. She offered practical solutions to achieve this, such as ‘bringing in people within your board in your strategic thinking, consulting with them. But also things like joint appointments’. As for CJ, these solutions are focussed on universities and scientists as having the majority of the responsibility for achieving this. In support of this argument for scientific understanding by business, GD put forward the example of coal miners needing something of an understanding of what they are doing and what the hazards are. In support of this point he stated that

> I think there are many examples of where businesses need to understand science, and workers need to understand the science of their business; whether its just getting the right amount of bubbles in your bread when you’re baking, there are many examples.

AMA continued her discussion in support of the use of scientific evidence by businesses, as she argued that

> there's no evidence to suggest that any business that has relied on the evidence or that has innovated or has worked with, collaborated with a university sector is worse off - quite the opposite, businesses thrive when they do that. Every bit of evidence we have around collaboration - I think that is just one example of business and academia - shows that those businesses are more productive, more economically prosperous. You know, you're a fool if you don't do it.

AB put forward a different perspective on collaboration and innovation as he focussed on the practical application of science in business and industry. Like IC, he put the responsibility on businesses to lift their game, stating that

> I also have a view though that business and industry are not proactive enough in Australia in going to our engines of research activity, which is our universities, and pulling out of those institutions information they need. The mechanism is too much of the arrow flying out of the universities and not yet enough of industry jumping into universities and saying “well we want you to do x, y and z”.

Further to this discussion, AB raised a point of caution in relation to an enhanced relationship between universities and business, that a ‘negative is it is might just challenge the research independence of universities’. WA shared a similar concern in his earlier statement on the universities undertaking what is considered ‘fringe science’ for financial reasons and the messages this behaviour sends to society. Both WA and AB made note of the connection between universities and the medical industry. AB put it plainly, in that 'the health sector has been usually good at tapping into activity and drawing from knowledge in places'. AB was somewhat harsh on the responsibilities of the medical sector and the importance of translational medicine, as he stated that 'it is no good just doing medical research unless you've got that element of translating it into definite health outcomes – you're not achieving any meaningful outcome'.

In sum, the interviewees' commentary on the mediums by which to achieve a SEA identified that primarily universities and scientists have a particular leadership role in achieving this, and as the creators of knowledge and prosecutors of research they were seen as doubly important. The role of governments was also highlighted in the discussion, with a focus on having a leadership role in terms of direction of activity and investment in science and research. The business community featured to a lesser degree in discussions in terms of a sector that has a responsibility to improve their relationship and connection with the scientific enterprise. The use of scientific evidence in decision making by governments and business was a common theme presented throughout the interviews.

Whilst scientists and universities were not the only ones targeted, commentary about them and their 'special responsibility' was more frequent, identifying them as the primary focus of much of the conversation in creating a SEA. However, when asked the question 'who is responsible for achieving a SEA?' directly, the majority of interviewees identified 'everyone', and to a lesser degree 'themselves' as being responsible, then 'bureaucrats and government', and 'scientists and universities' followed.

AB and GD identified themselves as being responsible. AB remarked 'I am, me'. GD stated,

> technically that's me. I'm the senior public servant charged with running the Inspiring Australia initiative, however you could argue that the Chief Scientist to Australia has responsibility, the Minister has responsibility, the Prime Minister has responsibility, the state and territory leaders have responsibilities, so you know the head of agencies have responsibility, and the heads of universities, the deans, the heads of research schools, the media you know, the responsibility is shared.

AB also identified the Chief Scientist for Australia, purporting 'Ian Chubb' as the immediate answer to the question. He later expanded on this by stating

> I mean I did off hand say the Chief Scientist as a position having a role, and to some degree I think that's a serious suggestion. It is - there is a person whose primary function is to give advice to government and in particular the Prime Minister…does have responsibility for making sure…scientific research activity in Australia is communicated in a positive and effective way.

All interviewees at some point identified 'everyone' as being responsible for achieving a SEA. Some like AB and WA acknowledged that it was a predictable answer, AB remarking, 'so the trite answer to any of these questions is that everyone is responsible'. Further to AB's statement, WA highlighted the complexities of the communication environment with the statement that 'everybody has a role but they're all different roles I think. Yeah, that sounds like the sort of question (sic) a bureaucrat says when they can't work out what the right answer is'.

IC and AMA emphasised the importance of understanding and the availability of information. IC proclaimed that 'Well everybody is responsible. I mean in a serious way information and capacity to learn about it ought to be available to everybody, and everybody has a responsibility putting that up'. AMA expanded on this view:

> it is not about pushing information to anyone, it's a responsibility, an awareness that we should all have what we need to be scientifically engaged because we are all better for it. I think that we are all absolutely responsible and have a part to play.

AMA made note of desired outcomes of the 'literacy or understanding, more awareness of the importance of that...by each of those sectors is critical, and so they each have a responsibility, it will do no harm - it will in all likelihood do them good'.

In addition to stating 'everyone is responsible', some interviewees were specific in identifying key sectors in society. AMA stated,

> all of us are responsible, I think students, policy makers, academics, governments, everyone that we've spoken about is responsible for a scientifically engaged Australia. We will not be worse off if we're better engaged, and everybody has a benefit to reap from that exercise. So it's all about responsibility.

CJ shared a similar more general view, as she remarked

> I think the responsibility is genuinely joint and we won't get anywhere unless everyone plays their part. People need to understand what their part is, so they are not just saying that they are responsible but 'my god it is all too big I can't I can't manage it'. But government is responsible, the scientific community is responsible. The community at large, you know, could open their ears a bit more sometimes.

The potential and realised roles of Universities again featured often in the interviewees' discussion. WA identified universities as the centre of activity, stating that

> all of these things [universities, community, education beyond universities, governments and business sectors] which you have so carefully set out…I think every part of society is responsible for its own bit, you know here is where things are generated [points to universities on the diagram] and so that's the kind of base really.

WA retained his focus on universities as he returned to his earlier commentary where he posed the idea of an 'ecosystem' where 'everything is a bit dependent on everything else', and all sectors have a role to play. He outlined that

> its not A is going to drive B – this [universities] is the only place new stuff comes from. But these two bits [business and community] are the bits that should be benefitting from a more scientifically engaged community, country. So you know the other way to answer that would be think not to try and answer your question but to say, that is a question. Who is responsible for what?

CJ raised a similar point in her statement, 'I think trying to lay responsibility at the feet of any one group is probably not the best way to do it'. However, it is of note that CJ was a strong advocate for scientists and universities as primary communicators and taking responsibility for communication.

GD's reflection on the current environment highlighted the shared belief that everyone has a part to play. GD added to this sentiment, stating that many are motivated by their own self-interests first. He outlined that

> I think there's broad recognition now that we're in it together, traditionally individual organisations are in it for their own end first, if I can put it in those crude terms there…but our [Questacon's and Inspiring Australia's] job is to sort of get them all to work together for the common good at a higher level. So there's times when they compete for resources, but there are times when together we're stronger, we can work better and you know we can make a case for the whole sector.

GD elaborated on this notion of coordination of activities in discussing his role, which is to 'redevelop the [Inspiring Australia] strategy' in that

> it's everybody's responsibility, but it needs coordination, and without coordination it's like an orchestra with no conductor. So you've got competent musicians playing their instruments but no one is going to play in harmony together to get the full symphony.

Perhaps not surprisingly, due to his responsibility in delivering the IA strategy, he made a point of the need for a central point of communication. He remarked that

> there is a gap and there has always been a gap, and that's why there is a problem. So somebody has got to provide a central point of coordination and focus to be a catalyst, and a leader…a leader that encourages everyone to go in a particular direction at a particular time.

AMA shared her own experience with IA, noting her support of the IA strategy and GD's views for the need for central coordination. She reflected,

> if I draw on my Inspiring Australia experience, sure that they have an important, important role in national coordination and showing leadership there. …There's definitely a role, a need for national coordination. Often these things don't happen spontaneously on their own and often it's about creating good networks – so you need that leadership. I think Australia actually does it better than we give ourselves credit for. Inspiring Australia's unique – there is no other program, policy, or national coordination and leadership of science communication and science engagement in the world that is anything like it, not even remotely.

Despite AMA's support for national coordination, she added that

> it is up to every individual, every university, I think to practice some of the things you know, and use those mechanisms that I spoke about earlier to strive to be more scientifically engaged.

Summary of theme 2

In terms of the institutional mechanisms to create a SEA, the interviewees identified universities as being central to this as they are the main promulgators of scientific research. The interviewees gave universities, and to a lesser degree other research agencies, more responsibility than other sectors, with the view that they have a duty to communicate. However, they thought that the responsibilities of universities were only part of the solution. Government was identified as having a profound role in creating a SEA, primarily due to its leadership capacity and the influence it has, in particular through the 'powerful voice of a leader'. Scientists themselves were identified as having responsibilities in that they should be taking on an advisory role in briefing governments and ensuring that mechanisms are put place to enable and encourage evidence based decision making by governments – an ideal and key outcome in creating a SEA. Yet, not all interviewees agreed on who is responsible for facilitating or ensuring evidence based decision making: scientists, governments, or both. The investment in science featured as a key institutional mechanism in creating a SEA motivated by the belief that there is an implied link between investment and output. Investment took a variety of forms, as incentives to stimulate connections between business and science, and as a way of controlling the complex relationship between governments and government agencies, and universities and research institutions in terms of both funding and in monitoring. The business sector was identified as an area for improvement in that businesses need to become more proactive in their relationship with science and use science to inform business decisions and innovation, and this in turn will benefit businesses; noting that the responsibilities and motivations of businesses differ to that of universities.

In response to being asked who is responsible for achieving a SEA, the majority of interviewees identified 'everyone' and to a lesser degree 'themselves' as being responsible, followed by 'bureaucrats and government' and then 'scientists and universities'. The complex relationship between the sectors and shared responsibility of creating a SEA was discussed by all interviewees.

Research Question 3: 'Is There a Discrepancy Between Theory and Practice?'

The third research question addresses the interviewees' views of the disconnect between the theory and practice of science communication, where one-way models of communication remain persistent despite the recommendations from academic and government literature for a shift to two-way models of communication. The emergent themes from this discussion highlight the disparity of views and confusion that exists around the reality versus the theory of science communication. Some interviewees challenged the notion that one-way methods of communication remain dominant. Some argued in support of one-way communication in achieving particular aims. All interviewees were advocates, whether direct or implied, for mixed model communication, which uses one-way communication as part of a broader communication package. In addressing why the discrepancy exists, many attributed it to a societal or generational transition that would resolve the disparity over the passage of time.

When first asked if the discrepancy between the ideal and reality of science communication was a problem, some interviewees challenged the sentiment. AB retorted 'it depends if I accept your premise', CJ remarked 'that is a very complicated question', and WA commented that it is 'not straightforward'. GD presented a different view:

> I am going to challenge that sentiment because that would have been true 20 years ago, possibly 10 years ago, it was monologue rather than dialogue. I think these days there is a lot of recognition that it needs to be a conversation.

GD went on to discuss his belief that 'people don't accept that' old model of monologue and that is 'why public understanding of science has evolved to the slightly better acronym of awareness and then became engagement'. GD did not comment on the persistence of one-way communication; rather he remarked that

> I think generally there is a broader awareness, and lots of young scientists in particular are actively seeking the skills to build up their competency to speak with the media, to engage with the media, to communicate via a web blog, so I think that it is changing and I think that recognition that it has to be dialogue.

AMA did not challenge the sentiment, reflecting that 'Yes and no. I'm not surprised that it [one-way] remains a dominant practice'. IC did not challenge the sentiment either; instead he spoke about how 'society is changing' and the need to adapt as things change, that he is a firm believer of adding to 'your repertoire' rather than 'tossing stuff out because they're old'. CJ shared a similar view to IC in terms of the evolution of communication models, saying, 'I think making a strict divide between the old and the new is silly, because the new is a genuine extension…from the old'.

Whether or not the interviewees agreed with the sentiment, there was broad consensus that communication models have changed over time. CJ discussed how

> the models of communication have changed so much in the last couple of years…in the last five years we have seen a fundamental change from what you would describe as one-way broadcast at you or whatever, to a world in which people genuinely interact about stuff, or generally – electronically usually – but that is relatively genuine.

WA remarked on how it is a complex problem and that it is

> not straight forward, and if it was all to do with very good messages, very good fact sheets from NHMRC or some other government body, that's why it is hard really. If it's just a matter of broadcasting the facts we wouldn't have any climate skeptics or anti-vaccination people, and science would be better funded.

AB disagreed with this question, saying 'being more interactive is not necessarily an answer'. AMA offered an alternative view on the apparent shift to 'engagement' from the perspective of the public, in that in that 'they [the public] don't have to articulate as being scientifically engaged, they probably never will. It's our kind of professional term isn't it'. CJ also commented on the perception of modern communication methods, saying, 'I know there is a fashion for saying only interactive communication now has an impact…I think broadcast still genuinely has an impact'. AB shared CJ's view on the benefits of one-way communication:

> but the telling of stories in whatever form…I don't think it is an improper way of communicating what you are doing. I mean it's to say, okay you can't just tell a story about good research, you have to somehow add something else onto it to have it have any value; and I am not sure I completely agree with that.

AB expanded on this statement by presenting various analogies, from including the director's narrative when watching a DVD, to reading a book versus going to a book club, and how when viewing artwork you can have either a 'silly superficial conversation' or an enriching one about it. AB did argue against himself here, reflecting that

> maybe there is a value in having a conversation or a more interactive reflection on what you've just seen or heard. And you could argue – so I am arguing against myself here. I think my first premise is true, you don't necessarily have to have…something else to make something valuable.

Like WA, AB identified the complexities of the problem. However, AB added that there are times that you ‘must have a whole other conversation about what you do as a consequence’ of particular scientific findings, as ‘there is a whole lot of consequences around that which isn’t always science, but it’s something you absolutely have to have lots of two-way input and using the word conversations around it’. Despite the complexities and evolution of communication models, CJ put forward her view in that

> I know there is literature that indicates that old fashioned mainstream broadcast (as I call it to cover all that stuff) is not nearly as popular as it used to be and not the way of the future. I think saying that it is completely dead and redundant is silly.

Throughout the discussions there were many instances of the interviewees themselves commenting on the persistence of one-way communication methods. For example, WA explicitly made note of how organisations are still using these methods: ‘the NHMRC, we can put out fact sheets’.

CJ, AMA and IC identified the public as still active consumers of one-way mechanisms. CJ stated how ‘people still go to things like…the ABC news’. IC shared this view, in that ‘in Australia there’s a whole generation of people who are not lined up on Facebook, or twittering or whatever…so some people still read newspapers, some people still watch the news and documentaries’. AMA added to this, commenting that media in general are one-way and that ‘newspapers, blogs, any form of media is going out to people and that is kind of one-way, but that’s where people get their information from and then they might respond differently’.

Many interviewees identified a need for one-way communication in modern communications, primarily with the public. CJ discussed the need for one-way communication in times of crisis or in an emergency, a view commonly shared in the academic literature. CJ stated that ‘people still go to it [ABC news] when something terrible happens, so when there is a bushfire or a disaster they need a trusted mode of broadcast’.

AMA offered a different perspective relating to the need for one-way communication, in that it is ‘one useful mechanism for engaging them [the public]…to begin with’. She put forward her support for one-way communication models in that there are instances when ‘you do need to go out to people for them to be drawn in’ and that ‘one-way communication is one touch point, one opportunity for them to be engaged’. AMA held a strong view that one-way communication is ‘particularly successful, and there is a legitimate role for that one-way communication to get them in’. She reflected on her past experience in running events, remarking that ‘the practice…[used] was pushing in one direction, but it was successful, extremely successful.’ She went on to add that ‘I don’t know that success is necessarily two-way communication when you are only speaking to the engaged’, commenting on how she believes engagement can only occur when the initial ‘hook’ has been made, and that there is a legitimate role for one-way communication in creating that ‘hook’ and reaching out to the public:

> but as I said earlier, incorporated in that [one-way methods of communication] should be a desire to have the disengaged engaged, and once they’re there give them a hook to remain interested or want to know more or engage in whatever way is comfortable in their lives or relevant in their lives.

AB was also an advocate for the use of one-way communication models, yet questioned, ‘do you need to do something else as well?’ He presented a pragmatic view on the benefits of one-way communication, as he argued that

> there are some things in science that are direct and absolute and complete and self contained, and so you don’t necessarily need to talk about them any more because it’s just there. So there is no extra value add.

CJ shared a similar view in that ‘I think that there is still genuinely a place for really clearly expressed, well argued – I won’t call it broadcast – long form written articles that people then genuinely read and then interact with either the authors or other readers’.

All interviewees touched upon the notion of mixed methods communication, with support implied in their commentary. IC spoke of the need to ‘use everything that is available to you really’, as opposed to AMA who focussed on one-way as the initial trigger as ‘one-way communication is one touch point’.

AB offered a different perspective. His support for mixed models of communication was implied in his discussions about times when you need to add value, arguing that ‘there are some things you can just tell people…but you have, you need to have a much richer conversation around what it all means and how it all fits together’. He went on to identify how this is ‘often where it moves away I think from science you see, into the humanities space. It is actually about how people are trying to interact within an environment’. In exploring this view he remarked, ‘now is this science, well it’s research, it’s important, and you have to have lots of aspects considered in a multidimensional way, and I’m all for that, I think that’s really important’.

CJ spoke of the evolution of communication models, making note that ‘we are getting this combination of different kinds of mediums’. She went on to discuss how current communication mechanisms have changed, whereby a

> great opinion piece of 900 words you put…up on *The Conversation* website, which is sort of kind-of a traditional old-style way of doing it, but then there are comments and then there is a discussion that goes on. And so I would describe that as a combination of relatively old style broadcast mainstream media and the evolutionary sort of you know exchange of ideas stuff.

Here CJ made note of the internet in enhancing broadcast communication and in turn mixed methods of communication. She went on to discuss the modern role of broadcast media in crisis situations too, mentioning a

> woman who got a whole bunch of awards for setting up a social media site right in the middle of one of those bushfires and doing the sort of coordination… that tapped into the ABC's resources, tapped into the rural fire brigade's resources really made a difference to how things worked. So those things can work together.

As discussed earlier in the mechanisms section, the internet again featured heavily as a response to mixed methods of communication and the evolution of communication. CJ discussed this, giving an example of a recent conference which used live streaming, stating that it is 'actually broadcasting what you are doing, out to a bigger audience and allowing them to come back in' in terms of feedback though discussion in online forums and blogs. Further to CJ's views, GD made note of media and blogs as mechanisms for real dialogue, with his statement:

> I think generally there is a broader awareness, and lots of young scientists in particular are actively seeking the skills to build up their competency to speak with the media, to engage with the media, to communicate via a web blog, so I think that it is changing and I think that recognition that it has to be dialogue.

Here CJ and GD have identified blogs and websites as modern methods allowing two-way communication. Others commonly referred them to as one-way methods, for example AB used the phrase, 'one-way traffic of blogs.' AMA offered a different view as she commented on how the internet has enabled these new mechanisms that can be both one-way and two-way:

> I do take the point that the science communication sector….do a lot of pushing out of messages. I'm not entirely uncomfortable with that – we'll get better at communicating things, there's a lot of two-way interactions in things. The kind of classics that you're forever seeing are the I f-ing love science [blog and social media pages], things like that which is kind of pushing out of information, but it's very interactive, it draws people in, it attracts. Great, terrific.

IC put forward an entirely different perspective as he discussed how websites have become a source or receptacle of information, with the statement, '[a] bunch of people who stumble across it or go looking for it realise that there's a website with all the stuff that the Chief Scientist does on it and sometimes they find it interesting', describing their use as more passive and one-way than other methods.

IC raised concern in relation to the use of blogs and the internet as a ‘big change, that’s the real change’, unlike his colleagues cautioning that ‘I don’t know that it is better cause what you’re doing is getting information out that stays there forever…now everything is discoverable and lives forever’. AB shared a similar concern, as he remarked how it

> give[s] you both the capacity to have lots and lots of different voices, but also the danger that you just listen to voices you like, so you switch off from the diversity of voices. So you actually becoming more narrow in your perspective of the world than you ought…because you’re going to be talking to like-minded people and it just focuses in.

Concern over the public’s information seeking behaviour was raised by many interviewees in relation to the discrepancy in the theory versus the reality of communication. IC remarked, ‘I don’t know that just telling them stuff works anymore’ and that ‘to get the public to engage they’ve got to engage with you, otherwise you’re just telling them stuff’. WA shared this view in that ‘you can push what you want at people and if they don’t want to hear it they won’t hear it and if it’s not touching their lives at the time it won’t touch their lives’.

WA presented a different aspect in relation to the discrepancy between theory and practice with respect to the perceived success of dialogue events, as he remarked that

> dialogues are not always good if you don’t get the outcome you want. And that’s the danger - you can talk all you like and have good discussions leading to a moderated position, but if it is not the right position it doesn’t actually help.

GD also discussed dialogue with the public, presenting a different view, as he stated that ‘dialogue is only important if it leads to something…if they feed into policy making. Otherwise it’s just talk…you’ve got to make sure that the outcome actually feeds into something useful otherwise people get disenchanted’. AB also discussed the societal impacts of science, in relation to the differences between the absolutes of science. He argued that

> I think there are some absolutes in science and there are some things that you measure that you don’t need to have a conversation about actually. Now you do have to have a conversation about the impact of [global] warming and how people respond to it and all of those other things.

The latter is where he sees the role of the humanities and science communicators in addressing the societal impacts of the science.

In response to the question about why the discrepancy between theory and practice exists, interviewees offered a broad variety of views from the idealist to the pragmatic as to the persistence of one-way methods of communication. Natural evolution was identified by many of the interviewees as being responsible for the discrepancy. IC reflected that 'the balance will change with time', CJ remarked that 'I think it is a cultural and I think it is a generational thing', AMA shared 'I suspect there is a bit of natural evolution around these things', and GD stated 'there is a time lapse in terms of awareness and understanding'.

Societal change was highlighted as being in part responsible for the discrepancy and was further discussed by CJ. She reflected that 'I think society is changing…things move and move on and you've got to adapt to it and use it'. Her critique was not restricted to the public; she also commented on science communication practitioners, in that 'I think science communicators are like everyone else in that they need to move on a bit faster'. CJ went on to discuss how

> it is difficult to keep up and we are in a weird spot at the moment where some models…are dying but new things are evolving all the time. But sometimes new things evolve and last about 30 seconds and drop off again.

CJ was the most profusive on this topic, concluding, 'there is always a lag; there is just always a lag. I mean embracing a whole different way of communicating is not something people do quickly or easily'.

GD offered a different view. Commenting on the situation from the perspective of the communicator, who is often a scientist, he noted that

> it is much easier for a scientist to go and give a talk and think they're communicating, it's just time efficient and it's much easier…so that [public lectures] sort of stuff is inevitably going to reinforce that type of behaviour.

GD's discussion was focussed on the role of the communicator, and in doing this he noted that 'scientists are often strongly opinionated, and that again tends to support a more monologue type approach'. He went on to offer a solution to this, raising the issue of training and adequate skills as being a factor that can contribute to the success of these activities. He stated that 'scientists are not generally well equipped to have those conversations, to have dialogue, because they generally don't get any training…that's a deficit that needs to be addressed'. WA's view was also focussed from the perspective of the communicator. In response to why one-way communication remains dominant, he said, 'because we can', before going onto discuss how

> the NHMRC...can put out fact sheets on vaccination or anything else we can do - that that's our thing. What we can't do is, you know, 200 of us go around the country whipping up interest out in the community, because that's not who we are or what our role is.

WA's discussion highlighted an interesting perspective that large highly organised institutions are able to disseminate information where others cannot. He remarked that 'the more organised something is the more it can push out'. Further to this, IC commented on the benefits that one-way communication enables in discussing the creation of content. IC stated that

> I publish stuff in various media outlets and cause it's a way of getting stuff out fairly efficiently on a scale that I want to get it out. If I wanted to reduce everything to 140 characters or something then I could. …But sometimes your message is complicated and you've got to take advantage of the opportunity that space gives you to create the message in the way that you want to get out, and its efficient. You can get to a lot more people on social media that's certainly true. But to get a complicated message out by writing an op ed piece for the right newspaper flavoured in the right way to attract the readership of the newspapers…then I think that's a useful plank and then you put a platform with radio.

However, AMA put forward a different perspective to the others on the persistence of one-way models of communication. She reflected on current science communication practices and argued in support of the legitimacy of one-way communication, not as a consequence or a convenient method of communication, but rather as a successful one in its own right. In support of this, she explained that it is

> because we haven't thought of a better way. I don't know that there are any ways put forward that people go 'oh no, that's ridiculous, we shouldn't do it that way'. I just think we haven't actually explored other means and there's probably some success in what we are doing. There has got to be some success for it to continue.

CJ put forward a similar view in support of current practices and the benefit in one-way communication. She challenged the question through the statement that

> if what they are saying is that you've absolutely got to have everyone ditch this model and shift to the new one, I would probably challenge that a bit. I think it is much greyer than that…I mean you know, fear of change is always a factor.

AMA continued her discussion on the topic of the relevance of one-way methods of communication, as she remarked that

> is it the only way? No, it shouldn't be. Is it technically a disconnect between a reality and theory? Yes, absolutely. But I think part of that reality is not just about engaging people, but seeking to give them a context than enables them to continue to be engaged….Should we think of other ways? Yes, we probably should.

AMA's commentary sought not to criticise but reflect on the perceived disconnect in the Australian science communication environment, and in doing so highlight the present complexities surrounding creating a SEA, and the science communication models by which to achieve this.

Summary of emergent themes

In response to the third research question investigating if there is a discrepancy between theory and practice of science communication the interviewees highlighted the disparity of views and confusion that exists around the reality and theory of science communication. It was apparent from the interviewees' discussions that while not all shared the same opinions, there was both implied and direct support for the use of one-way methods of communication as a useful mechanism in achieving a SEA. A genuine need for one-way communication in specific circumstances was identified, such as in crisis communication and some interviewees believed that the broadcasting of fixed messages or the telling of stories on there own is of benefit and a legitimate way to communicate. The media and the internet featured throughout the discussion with some interviewees identifying the media and the internet as one-way, while others identified their capacity for two-way communication. The internet was discussed as enhancing traditional broadcast media by enabling feedback, as it can be used for both one-way and two way communication. Cautions arose with respect to the use of the internet in that it can present a breadth of opinions, but there is a real danger that you switch off to the diversity and become narrow. The internet also featured heavily in the discussion on mixed model communications, a notion that was touched upon by all interviewees with their implied support.

The most common explanation for the discrepancy between the reality and theory of science communication and the persistence of one-way methods of communication was attributed to natural and cultural evolution and societal changes. In addition to the cultural lags, the convenience and common practice of one-way methods of communication was noted by the interviewees, each with their own perspective on the merits and persistence of one-way communication. These reasons included: motivations relating to the default, time efficient and easy nature of one-way communication, which suits the communicator; the ability to craft a particular or complex message; and simply that it remains a suitable model to satisfy the communicator's aims in the absence of a better way.

Chapter summary

The variety of views put forward in response to the interview questions highlights the ambiguity and varied perspectives surrounding the science communication environment in Australia, in particular the disparity between the theory and practice. What is clear from the discussion presented here that there is no unified position or consensus on what a SEA would constitute, how or through what mechanisms is it to be achieved, and who is responsible for this undertaking, though often a number of participants agreed on specific points. The emergent themes presented in this discussion begin to identify the answers to these questions, but it is far from a unified position on science communication in Australia and how to achieve the aim of a SEA.

CHAPTER SIX – CONCLUSION

This thesis provides a snapshot of current thinking in Australia about science engagement from the perspectives of the academy, science communication practitioners, formal government policy, and key opinion leaders. The dominant theme that emerged from these four distinct data sets speaks to the motivations of economic pragmatism in driving the agenda of creating a SEA. Driven by the desire to safeguard future investment in science, bolster a dwindling economy through more science graduates or reduce the spend on public healthcare by empowering people to make better life choices, I have identified that it is economic concerns that underpin much of the motivations of the SEA agenda.

A nuance to this argument relates to a less prominent, yet still important, motivation – that of science appreciation. Science appreciation encompasses those motivations that speak to the love, value and treasuring of science. My results emphasise the desire here is to create a nation that is not only inspired by, values and supports science, but also one that is empowered to use and embrace science as part of everyday life.

Economic pragmatism

Unlike science appreciation motivations that are largely focussed on public change at the individual level, economic motivations are focussed on the collective, resulting in societal, not individual benefits. Largely, but not exclusively, relating to policy agendas, I have found that motivations driven by economic pragmatism relate to collective or shared problems, problems that when rectified are believed to lead to enhanced economical, societal, and environmental benefits.

The overarching theme of the Inspiring Australia (IA) strategy is the ‘national framework – local action’ approach to coordinated science communication across the country. This approach calls for greater coordination of activities and effort to both coordinate the messaging and to enhance the effectiveness of communications by minimising duplication of effort, resulting in collective benefits. The IA strategy and its subsequent Expert Working Group (EWG) reports are evidence of these economic motivations as they directly described the aim of increasing the return on, and safeguarding the future of, investment in science. The majority of the EWG report topics were all centred around, or had direct links to, the nation’s economic standing. The key features of these reports relate to the areas of agriculture, mining, fisheries, tourism, and Indigenous knowledge of the land and environment and how they relate to industry and the economy. The IA strategy provided further evidence in support of outcomes driven by economic perspectives. IA sought to encourage more students into science based careers with the view that this will lead to more ‘home grown’ scientists. This aim was motivated by the belief that a greater number of science graduates will directly benefit the economy.

Economic motivations are not just restricted to the IA strategy. Commonalities can be drawn across the data in terms of the sought after communication outcomes. I found that a significant proportion of desired outcomes relate to the perceived economic benefits that will result from communication initiatives. In terms of the public, ideal outcomes would be the acceptance and adoption of emergent technology, along with the desire that the public would be supportive of developments. Closely linked to this point is the desire for informed participation by the public in policy development, guided by the belief that if the public is both informed and involved early in the development process then they are less likely to veto innovation and development. These motivations of public participation are not primarily desired because of a principled belief in democratic control over public policy, but rather as a means of protecting the investment in research and development.

A primary example that continuously reasserted itself within the data related to informed decision making. The shared view is that it is important for the individual to be able to make informed (and hence better) decisions, resulting in positive flow on effects not only for the individual, but also for society as a whole. The one example of this that was raised repeatedly throughout the data relates to population health, guided by the belief that people able to make informed and better decisions about their health will inevitably lead healthier lives, resulting in requiring less support from the medical system, thus benefitting all of society.

The notion of enhanced outcomes from informed decision making is not just restricted to the public, but also governments, business and industry. The interviewees in particular emphasised the importance of evidence based decision making in these areas, with the view that it would in turn result in economic benefits, both collective and individual, but also would enhance the relationship with, and potentially future investment in, science.

I have identified some important ideological trends relating to the future investment in science. There exists a desire for business and industry to take a greater role in supporting science, not only to use science to inform their decisions but to actively invest in research and development. This motivation is driven largely from the IA strategy and policy leaders, who also shared the view that universities and practitioners of science need to become more proactive in exploiting links with research and industry to diversify their income streams.

The communication of science is an integral component in creating a SEA. In addressing the aims outlined in the IA strategy, I found that the various communication mechanisms identified as having a key role in delivering on the aims of a SEA agenda are largely guided by economic considerations. Some mechanisms such as the media and new media and the formal education system are existing mechanisms able to be tapped into; others such as citizen science are new initiatives identified as part of the IA strategy and supported by academia and policy leaders.

As discussed, the media, new media and the formal education sector are largely dominated by one-way methods of communication. The continued use of one-way communication is intimately linked with economic benefits. Other arguments exist in support of its continued use, yet one clear attribute relates to its minimal and efficient use of resources, be it time, money or its ability to reach a broad audience in a tight time frame. Simply put, despite its other merits, one-way methods are more economical to administer than participatory approaches to communication. In addition to these economic factors in support of one-way communication, I have found that for many of those involved it remains a legitimate and even ideal method of communication.

Citizen science initiatives differ from the other mechanisms identified as being central to the SEA agenda as they are more participatory in their approach. Citizen science has long been identified as one of many useful two-way methods of communication of the PAS/PEST era. Here I found that it has had a resurgence in the latest policy document associated with the IA strategy and was raised as a key mechanism by the interviewees. Its appeal lies largely in the economic benefits it can generate. Many two-way methods of communication are resource intensive to deliver, often making them less desirable. However the notion of citizen science is favourable as it enables the public to participate in science, and by doing so, public volunteers contribute to the construction of knowledge – essentially it is crowd-sourced scientific research.

The target audiences identified under the IA strategy are reflective of both the underlying economic and science appreciation motivations. The authors identify students, and their teachers, as the primary audience, motivated by the economic aim of encouraging more students into science based careers. Yet the other key audiences identified as part of this strategy – those considered not already engaged, and to a lesser degree Indigenous communities and those where English is a second language – fall within the remit of both economic and science appreciation motivations.

Science appreciation

Unlike economic motivations that dominate much of the discussion, motivations of science appreciation run as an undercurrent across the data. Even as a minor theme, these motivations have a significant influence on understanding what it means to create a SEA. Motivations of science appreciation tend to be broad and aspirational in nature, and are often focussed on the public. The general notion is that in a SEA, the public would love and value science, acknowledge its benefits to society, be supportive of scientific advancements, and generally have a positive relationship with and trust in the institution of science.

Motivations of science appreciation are in part focussed on empowering the public, driven by the belief that a public that values and trusts in science will be supportive of developments that will lead to improved outcomes for both the institution of science and society as a whole. These motivations are not just directed to the individual, but to all facets of society, the community as a whole, governments, institutions, business and industry. However, these motivations are largely focussed on public change.

It is apparent across all data sets that those who exhibit the desire to achieve the aims of science appreciation within the public are leaders – community, industry, organisational and policy leaders. However, despite these aims my analysis highlights that in reality the primary responsibility for communicating with the public still falls to scientists. Above all others, scientists are identified as not only having a vested interest in the public's relationship with science, but a duty to communicate, because they are publically funded. This view is guided by the belief that this will result in benefits to the institution of science, not just society.

My findings identify that those communication initiatives best suited to address the motivations of science appreciation typically fall within the remit of general science promotion. These initiatives are broad in nature and often not targeted at any specific audience, instead communicating across differing sectors indiscriminately. The key sources surveyed advocate the use of participatory or two-way activities as being well suited to address these goals, as these activities tend to focus on building positive relationships with science. Common activities that address this motivation of science appreciation include science centres, consensus conferences and discussion forums. However, these activities are not exclusively motivated by science appreciation. Multiple motivations are evident, in consensus conferences and discussion forums in particular, as often the intention is a genuine desire for greater democratisation of decision making.

Significant influences on understanding the SEA agenda

I have found that the conflation of terminology has had a significant impact on understanding what a SEA would look like. Conflation and imprecise definitions exist throughout the data in defining and discussing 'engagement'. This conflation, in particular the use of the term 'engagement' as a synonym for 'communication', made it difficult to ascertain the motivations behind, and the desired outcomes of, the communication activities under discussion at any point.

Conflation is also evident in the data in regard to the deficit model and one-way methods, as often these two terms are used interchangeably. This conflation becomes problematic when trying to separate and understand the nuances of these models, as one-way methods were implicated in the demise of the deficit model. It is often assumed that all one-way communication is deficit model communication and vice versa. I found that this is not the case; not all one-way communication is founded on a deficit view of the public. In addition, evidence exists of the persistence of both deficit model and one-way methods.

Despite this uncertainty surrounding the terminology there is evidence in the more recent rhetoric of a practical shift towards more two-way methods. I found that scholars, practitioners and policy leaders call for greater use of participatory approaches to communication, such as citizen science initiatives and greater participation in public discussion and debate. It is evident that this shift is largely dominated by economic motivations in terms of the communication models selected, the desired outcomes, and in the subject matter addressed. The EWG reports are largely motivated by economic concerns, yet the interviews with the policy leaders also include elements of motivations of science appreciation. I found that the dominant feature of the EWG reports was the emphasis of the importance of local knowledge in both preserving this information base and in informing research, particularly in the areas of agriculture, deserts and tropical environments, fisheries and marine science. In addition, the language used throughout the EWG reports is reflective of more participatory and two-way methods, yet on closer inspection I found that the outcomes are still focussed on public change.

However, one of the most significant findings of this study is that in practice science communication remains dominated by PUS-style motivations of the desire to induce change in the public through the use of one-way methods. I have found that continually reasserting itself throughout this study is the desire for knowledge construction or transfer in the public. The desire to tell someone something they do not already know is inherent to all communication. But I have found that there appears to be three facets to this that are closely related under the remit of PUS-style motivations: the desire to induce some sort of change in the public; the desire to tell someone something they don't already know; and the desire for knowledge construction (or education). Evident across the entire data set is the desire for public change. It typically manifests in the belief that greater knowledge will lead to better decision making that will benefit the individual, society as a whole and the institution of science. This facet is intimately linked to economic benefits. The desire to tell someone something they don't already know is more prominent in the interviews with policy leaders. I found that this element is more likely to fall under the remit of science appreciation motivations. The interviewees shared the desire to communicate latest science discoveries and innovation development with the public, with the aim of generating interest and excitement. Knowledge construction is related to the desire to induce change through education. The most prominent example of this in the data manifests in the IA strategy, and to a lesser degree the interviews. The emphasis here is on the importance of formal education to enable the public to make educated decisions and to participate in informed policy debate.

Knowledge construction is intimately linked with one-way communication. As noted, part of the attraction of one-way methods relates to their ease of use, in particular their efficiency or economy, compared to participatory approaches to communication. They are cheaper, easier and often faster to administer, have a broad reach, are easily repeatable, and are ideal for communicating a specific message. Economic motivations aside, I have found that one-way methods not only persist, but according to policy leaders, scientists and some scholars and practitioners, are a legitimate method of communication. This view is supported by the case studies of science communication in action, the findings of the 2012 Metcalfe et al. audit, and the interviews with policy leaders. I found that one-way methods are an ideal choice when used as part of a suite of communication mechanisms, or particularly when required to communicate a specific message within a short timeframe, for example in crisis communication.

I found that science, society and policy do not operate in a vacuum. External factors, such as politics, policy leaders, stakeholders and practitioner requirements all exert an influence on the reality of science communication in practice. Evidence of this exists not only in the persistence of one-way methods but also in the ever increasing politicising of science. Political influences can be seen across all data sets but are especially pertinent in the evolution of the IA strategy. Evidence of this can be seen in how the EWG reports reflect the changing political environment with a greater focus on economic objectives. I also found evidence of political influence in the interviews with key policy leaders, who identify themselves as being primarily responsible for delivering on the SEA agenda. This finding is not surprising as some of these individuals are political appointments and all must operate within the political environment. In recent years science and science funding has become highly political. Underpinned by economic motivations, the link between science, technological development and the economy is more apparent than ever before. It is clear that governments see a greater role for business and industry in investing in Australian science, research and development. Science communication in Australia is no exception.

Closely related to the politicising of science and the motivations of economic pragmatism is the view shared across all data sets of safeguarding investment in science and scientific decision making. IA identified the need to encourage more students to study science and take up science careers as the primary way to deliver on these aims. Yet, some of these assumptions are based on flawed logic. A correlation does exist between more science graduates and an improved economy, but it is not necessarily causal. The missing component is the creation of more science jobs through greater involvement by business and industry.

This thesis creates a picture of the current aspirational view of what a SEA would look like; describing a nation that would see science as important and the prosecution of it for public good. A SEA would promote 'science' as much as possible indiscriminately across all sectors, without any specific agenda or consistent overarching vision, to a public that will accept and embrace it. The nation would be inspired by and value science, science will become part of everyday life, and more students will study science at every level of schooling. The public will have a greater understanding of and be more knowledgeable about science, where a lifelong connection with science will begin in the early years of formal schooling. These motivations are reminiscent of the agenda set out in IA.

The aspiration is that these actions will result in greater love and support for science, improved democratic decision making – resulting in better decisions; with flow on effects for the nation's economy particularly in the health sector. Policy debate will be informed by science, and the public will be supportive of emergent technology. There will be greater investment in science by governments but also by business and industry, with greater collaboration between industry and universities. Universities will become leaders in the communication of science, academics will be rewarded and formally recognised for doing so. Funding organisations will support communication projects and research through their competitive grants schemes.

The communication mechanisms used to achieve a SEA would be predominately one-way, dominated by social media and traditional news media. Everyone has a role in creating a SEA, yet there remains an emphasis on a top-down approach with institutional responsibilities to communication to the public. Playing a minimal role in this vision are participatory methods of communication, debate about science, and the active advocating for deliberative decision making. The vision presented here is far from a unified position on science communication in Australia and how to achieve the aim of a SEA. Academic literature aside, in many ways the evidence put forward in creating this picture forms a relatively unified aspiration of what a SEA would look like, and is in concert with much of the original IA report.

In relation to the academic literature what has emerged from this study is evidence as to the disconnect between the theory and practice of science communication. It is apparent that there are two facets of science communication – the scholarship, and the reality of it in practice. This disconnect is made evident in this thesis through the real world case studies of science communication in practice and interviews with key policy leaders. To create a better picture of what can be achieved through science communication, what is needed is a greater understanding by both scholars and practitioners of the nuances of science communication through the deeper understanding of the social studies of science.

The disconnect between theory and practice is evident in this study through the persistence of one-way methods and to a lesser degree the deficit model of communication. The relevance and appeal of one-way methods is discussed at length throughout this thesis. Not only does it remain a popular choice, it is often the default choice for many. Its appeal lies in its efficient use of resources and it remains the ideal method to use for the communication of fixed messages. One-way methods, in particular traditional and social media, currently dominate the Australian science communication landscape. This study highlights that this is likely to continue although there is evidence of small moves towards more participatory or dialogical communication, largely through citizen science initiatives.

In terms of these participatory activities of PE what has emerged from this study is that there does not exist a universal or unambiguous definition of the term 'engagement'. This term is often used as a synonym for communication, leading to confusion over its purpose and method. The ambiguity that surrounds the term 'engagement' is apparent throughout this study not only in the policy documents and through the interviews with the key policy leaders, but also in the formal science communication literature. In part, the inability to clearly define this term leads to the confusion over what it is meant to achieve and through what methods. The ambiguity may be responsible in part for the disconnect between theory and practice of science communication. Greater clarity over what is truly meant by PE, its definition and purpose, would enable more targeted activity and may lead to improved outcomes and genuine participation by the public.

In contrast to the academic literature, the view towards science communication in practice that has emerged from this study can be considered a 'softer' or more relaxed and inclusive approach to science communication in practice. This approach retains motivations of both the original PUS era, through education and knowledge building, but also the latter PAS/PEST era of science communication, through the active participation by the public through citizen science initiatives. What has emerged from this study describes an inclusive or 'open-slather' approach to science communication more in line with the mixed model approach to communication discussed by scholars Bonfil Olivera (2004), Lewenstein and Brossard (2006), Sturgis and

Allum (2004), Trench (2008), Van der Auweraert (2004), and Wright and Nerlich (2006). This approach is largely dominated by one-way methods, but begins to include considerations of two-way methods of dialogue and participation going forward.

The evolution of science communication from PUS to PAS/PEST attempts to address the consideration of audience through the notion of public participation. The language used in the formal literature has also evolved to be more inclusive, where public participation and dialogue are believed to enable the public to have their views put forward into the policy decision making process. However inclusive the language appears to be the motivations behind the activity remain primarily focussed on generating change in the public, and occasionally even retain deficit like motivations. Like the literature, the outcomes of the review of the policy documents and interviews key policy leaders also emphasise the desire for public change and also retain deficit like motivations. This is particularly evident as the desire to increase the public's understanding of science remains a primary motivator for science communication in Australia, guided by the belief that a better educated public would lead to enhanced benefits – all largely related to economic motivations. The motivations of 'science appreciation', again see the public changing their views towards science. Despite the strong emphasis on public change in this study there is evidence to suggest that there is a desire to generate behavioral change in other areas, again all largely under the motivation for 'economic pragmatism'. This change would mean that all industries, governments, and businesses would use scientific knowledge to inform their decision making, for business and industry to take greater responsibility in investing in Australian science and innovation, and for scientists to be more proactive in communicating.

It is apparent from this study that the nation's science agenda is influenced by the increasing politicising of science, and the communication of it. The IA report which describes the Australia's first national strategy for the engagement with the sciences outlines a 'national framework – local action' approach to communication. Funded by government and driven in part by their agendas this framework seeks to coordinate effort across the nation through consistent and centralised messaging. Further evidence of the politicising of science can be seen in the dominant motivation of 'economic pragmatism' driving much of the science communication agenda in Australia. This study has identified the priority areas for communication in Australia as the environmental, medical and health sciences. These areas were determined as being of importance to the future prosperity of this country, be it maximising farming and fishery outputs or minimising public health concerns. Overall this study grounded in the academic literature describes the science communication agenda for Australia, and through this it emphasises the disconnect between theory and practice of science communication. This study highlights the need for the development of a practical approach to science communication underpinned by theory, but able to satisfy the requirements of science communication in practice.

The limitations of this study relate to the selection of the interviewees. The interviews provide a snapshot of the opinions of key Australian science policy leaders and science communication practitioners. In order to create a high-level picture of understanding of those who directly influence science policy development in Australia it was most appropriate to target this selected group of individuals. Other scholars may wish to elaborate on this study by expanding the interviewees to include the opinions of the public, scientists, and professional science communication practitioners, for a broader view of picture of understanding of science communication.

In terms of future work, the two distinct agendas of economic pragmatism and how science, innovation and technology development can contribute to the nation's economy, and to a lesser degree the notions of greater love, appreciation and support for science within the community, provide an understanding of what a SEA would look like. While this statement is largely Australian specific and focussed on the motivations and desired outcomes, it is relevant to discuss the use of the communication models in delivering on these aims. I have found evidence that the reality of communication does not reflect academic rhetoric in terms of the methods of communication used. Recommendations for further research would be to build on the interviews with policy leaders to create a detailed picture of understanding of the science communication agenda in Australia from all facets of the Australian population; the public, business and industry, scientists and universities, the education sector, and professional science communication practitioners. In addition, while aspirational goals have been explored in this study, a future project might seek to create a more realistic picture of what is actually possible in achieving the aims of creating a SEA.

On a personal note, when I reflect back on this picture of science communication in Australia, the idealist inside of me still hopes that motivations of science appreciation will triumph. That we will create a curious nation that understands the importance of science, that is interested in and excited by discovery. As someone who is passionate about science, I am motivated to share my love for science and excitement of discovery with those around me.

However, in my opinion, the influence of the politicising of science, along with the growing concern that this nation is no longer 'the lucky country' emphasises the increasing desire to be pragmatic and invest in what will benefit the nation's future economic standing. It appears that science and the communication of science are no exception to this. But if I am honest with myself I am also motivated by economic gains. I know the impact that science can have, and benefits it can generate. Benefits not only to individuals, but also to society both in the immediate term and the future; both in terms of enhanced outcomes from informed decision making, but also in innovation and technology development.

I am not altruistic in my motivations, I am motivated in part by selfish reasons. I want to be part of an educated nation, one that collectively is able to make better decisions both at the individual and societal level, a nation that uses science at all levels to inform their decisions. That being said, as an idealist, I hope the motivations of economic pragmatism do not overshadow those of science appreciation. I hope that the people of this nation become deeply curious, that scientific discovery brings joy and excitement to all, and we value science for these reasons not just what it can do in terms of improving our economy and delivering a financial return.

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APPENDIX A

Centre for Antimatter-Matter Studies project development process details – topic themes

The 'Antimatter – does it Matter?' panel display was broken into the following five main topic themes, informed by the aforementioned five key messages and relevant stakeholders, as depicted in table 2A:

Table 2A

Thematic structure of the 30 panel display, key messages, relevant stakeholders in addition to CAMS and the number of panels assigned to each theme

Theme	Display structure	Key messages addressed	Additional stakeholder(s)	Number of panels
	Title panel			1
Theme 1	The history and unique discovery of antimatter	1		11
Theme 2	The myths, misconceptions and bigger questions about antimatter	1, 3		5
Theme 3	Practical application of antimatter and its use in nanotechnology	1, 2	ANSTO	5
Theme 4	The science behind Positron Emission Tomography (PET) scanners	1, 2	Siemens	6
Theme 5	Introduction and overview of CAMS and the science they conduct	1, 4, 5		2
	Partnership acknowledgements		ANU, ANSTO, Siemens	1

Theme 1: History of and Unique Discovery of Antimatter

This theme contained 11 panels. It defined what antimatter is, how it is made and stored for use, how it behaves, and the history of its discovery. This theme had a strong personal human focus in the story of discovery that emphasised its unusual mathematical discovery prior to being experimentally verified.

Theme 2: Myths, Misconceptions and Bigger Questions about Antimatter

This theme consisted of five panels highlighting the myths, misconceptions and bigger open ended questions about antimatter. It discussed how antimatter is not just a creation of science fiction stories, but rather it is real and has many applications. Under this theme the narrative goes on to debunk common myths and misconceptions regarding antimatter and its beginnings in science fiction. From antimatter propulsion, to antimatter as an energy source or even as a weapon; and explores the bigger questions of the asymmetry of antimatter and matter in our universe. This theme was designed to encourage the visitor to think more broadly about science fiction stories in terms of the real science behind the fiction, and to generate discussion through broader thought.

Theme 3: Practical Application of Antimatter and its use in Nanotechnology

This theme spanned across five panels. Informed by ANSTO, it discussed why antimatter is useful and some of its practical applications. This theme addressed what makes antimatter useful in our everyday lives, as it explored positronium and the antimatter-matter annihilation process as the key to its use. It also briefly addressed what nanotechnology is and how antimatter is used to probe the inner structures of nanomaterials.

Theme 4: The Science behind Positron Emission Tomography (PET) Scanners

Supported by Siemens, these six panels illustrated the use of antimatter in medical imaging in PET scans and the science behind these principles.

Theme 5: Introduction and Overview of CAMS and the science they conduct

The two final panels in the display concluded the discussion about the science behind antimatter with a summary of the science that is investigated by CAMS.

APPENDIX B

Centre for Antimatter-Matter Studies project development process details – design themes

Theme 2: Language Content and Layout

In consideration of generating 'holding power', information was layered hierarchically, and supported by relevant imagery and explanatory captions to give the visitor a quick overview of the panel without having to read it in its entirety. The written text was structured in a way that the opening sentences provided a brief overview of topics covered in the subsequent detailed text (DeRoux, 1999; Desmond, 2004; Mashantucket Pequot Museum and Research Center, n.d.; Western Australia Museum, 2006). The use of a thematic structure and the layering of information assists the reader and enhances their comprehension (Ballantyne, et al., 2008; Cooper, 1993; DeRoux, 1999; Desmond, 2004; Falk, et al., 1992; Holland, 2008; Oberlander, O'Donnell, & Mellish, n.d.; Serrell, 1996; Walsh, 2008; Western Australia Museum, 2006; Yates, 2008; Yung, 2008).

Other techniques employed to enhance the readability of the panels were used only where appropriate to do so to add value. These techniques included: attention grabbing and catchy titles, quotes that enhance the narrative, metaphors, analogies and rhetorical questions, and forced punctuation (Hohenstein & Tran, 2007; Pascolini & Pietroni, 2002; Serrell, 1996; Vieira, 2008; Walsh, 2008; Yates, 2008; Yung, 2008). In line with these recommendations the panel's opening title was phrased as a question, 'Antimatter – does it matter?', in an effort to engage the audience with the concepts of the exhibit, evoke curiosity and encourage further thought. Appropriate metaphors were used throughout to generate further thinking, and to bridge the gap of understanding by linking something familiar to the concepts or ideas trying to be explained respectively. To maximise the readability and accessibility of the written content, short sentences, active voice, minimal punctuation, hierarchical layering of information, sub-headings, and clearly defined paragraphs were used, and the average word count of 150-200 words per panel as recommended was adhered to (Vieira, 2008; Walsh, 2008; Yung & Kohlhagen, 2008). In the final stages of development the language was checked for any potential double meanings, culturally specific explanations or unclear meanings (Ballantyne, et al., 2008; Blunden, 2004).

Theme 3: Imagery

Image selection was guided by industry standards. The selected images needed to be of a sufficient resolution and format to ensure fidelity of the image when printed in the large format of the panel display (Walsh, 2008; Yung & Kohlhagen, 2008). Only technically good images were used; these included considerations of relevancy to the information presented, visual cues by the way of iconic images, simple images that depict only one main idea, have clear lines, no blur, red eye or out of focus elements, no unintended lens distortion or saturation and have accurate white balance (Ballantyne, et al., 2008; Harasymiv, 2008; Holland, 2008; Serrell, 1996; Walsh, 2008; Yates, 2008; Yung & Kohlhagen, 2008). As part of this process a surplus of images were identified, in addition to the number actually required for the project. This provided variety in choice to enable greater cohesion between the text and the imagery. It also provided alternative options if the preferred image was unobtainable. In an effort to minimise the cost associated with image procurement the use of private images was minimised. Instead images from government organisations and/or those available under creative commons were used where possible (Harasymiv, 2008; Serrell, 1996; Walsh, 2008; Yates, 2008; Yung & Kohlhagen, 2008). Image negotiation was a lengthy component of this project. Each image required a separate contractual negotiation due to its copyright (Australian Copyright Council, 2008), payment, size, proposed use and duration of display, and the context that the image is used in terms of the content it supports. The two images that were most difficult to procure due to copyright negotiations were the images of Starship USS Enterprise and Einstein.

Image selection was constrained by the complexity of the scientific content. Difficulties arose in obtaining suitable images that were scientifically relevant, visually appealing, high quality, affordable and currently available. To remedy this photographers and local artists were commissioned to create bespoke artwork for eight of the panels, specifically images of the laboratory and an artist's representation of scientific phenomena.

Theme 4: Physical Design, Positioning and the Final Product

To enhance the readability of the panels they were designed in portrait orientation, using contrasting design elements with dark text on a light background, with an appropriate font size and type – sans serif (Walsh, 2008). The graphic design of the panels was flexible in style to avoid visual repetition, enhancing its attraction and 'holding power' (Ballantyne, et al., 2008; Cooper, 1993; DeRoux, 1999; Desmond, 2004; Falk, et al., 1992; Holland, 2008; Oberlander, et al., n.d.; Serrell, 1996; Walsh, 2008; Western Australia Museum, 2006; Yates, 2008; Yung, 2008). The panel design used visual cues, as recommended by the literature, to enhance appeal through the following elements: font style and size, sub-headings, colour, style and spacing (Ballantyne, et al., 2008; Falk, et al., 1992; Holland, 2008; Serrell, 1996; Walsh, 2008; Western Australia Museum, 2006; Yates, 2008; Yung, 2008). The overall exhibit design was mindful not to overuse these features in the efforts to entice or entertain visitors, as Serrell (1996) stresses that visitors deserve respect, and they will appreciate exhibits that are not trivial.

The design of the opening panel differed from the body panels. The opening title panel was 800mm x 1100mm, featuring the name of the exhibit 'Antimatter – does it matter?' and the CAMS logo. The subsequent 30 panels were smaller in scale each measuring 500mm x

750mm. Due to the temporary and transportable requirements of the project, the panels were constructed from a durable material that was not easily scratched, allowing them to be frequently handled and transported, and included industry standard fasteners, hung in line with the visitors' centre of vision (Ballantyne, et al., 2008; Desmond, 2004; Walsh, 2008; Yung, 2008).

The graphical design of the project was undertaken in line with industry recommendations, by a professional graphic designer, Ms Iona Walsh. Ms Walsh had previous experience in designing text-based exhibits in similar Australian settings, and was paramount to the success of the project.

The overall design of the panels was consistent throughout. The same palate of bright eye-catching colours on a neutral base and attention grabbing design was used in an effort to compel the visitors to stop and read the panels. The design avoided the use of cartoony elements to avoid trivialising a serious subject, in line with industry recommendations (Serrell, 1996). The final design responded to the stakeholders' requirements, using the following key design elements to maximise readability: a descriptive title, significant body of text between 100 -200 words narrating the story of antimatter, a relevant supporting and often scientific image and an accompanying image caption, and credits where necessary. The addition of image captions was made late in the project development; their inclusion was in response to concerns raised by Questacon over the complexity of the content and the apparent lack of cohesion between the text and the imagery not being suitable for their typical audience. To compensate for this, panel captions were developed providing short bodies of text as a 'snapshot' of the panel's content, linking the text to the imagery and with content and language that was appropriate for the level of the typical Questacon visitor. In addition to these elements, 'side panel' sections or 'blue emphasis boxes' were incorporated into the design as needed to further explain complex scientific information, in an effort not to sacrifice completeness for brevity (Serrell, 1996).

APPENDIX C

Centre for Antimatter-Matter Studies project development process details – client-adviser relationship

The role of the adviser is to provide expert advice, prioritise actions, and to assist clients to succeed (FranklinCovey Co, 2007; Galvan, Anderson, Garrett, & Swift, 2007; Riedlinger, 2005a, 2005b). To achieve this, the roles and responsibilities of the adviser should be identified and agreed upon to avoid the potential of not meeting the client's expectations (FranklinCovey Co, 2007; Riedlinger, 2005a, 2005b; Sharpe, Anderson, White, Galvan, & Siesta, 2007). The client-adviser relationship can become complicated, negotiating 'confirmation bias' of the client (Jonas & Frey, 2003) and multiple stakeholders and their requirements - where the adviser must work to build consensus among between the stakeholders (Maister, Green, & Galford, 2000). The adviser must facilitate the discussions to build open avenues of communication between the stakeholders, and bring clarity to the problem sometimes by asking the hard questions (Metcalfe, 2005). Advisers use strategic questioning as an effective mechanism to encourage client openness, clarify meaning, unveil additional insight, or to direct the gathering of information (Sharpe, et al., 2007). The quality the client-adviser relationship can directly impact the success of the project; both parties, but in particular the adviser, must work hard to create a positive and productive relationship. The success of this real-world communication project was due to the positive and productive client-adviser relationship: my role as the adviser was to reconcile the differences in the stakeholders' objectives, between the individual stakeholders, and most importantly with the best practice recommendations for science communication. In delivering on the stakeholders' communication objectives the final project did not adhere to science communication best practice, namely the aims of the PEST era, rather it employed techniques associated with the PUS era. Irrespective of the choice of communication model, the final project was informed by the academic literature and took into consideration these recommendations employing them where appropriate.

As the adviser in this project I, in conjunction with another CPAS student Mr David Harcourt, undertook a series of focussed interviews initially with CAMS as the primary stakeholder to develop the initial content used for a public seminar developed in 2007. This initial body of work was built upon through further interviews with the primary stakeholder and then Questacon, ANU and finally ANSTO and Siemens. The purpose of these interviews was to ascertain the stakeholders' primary communication objectives in terms of the communication themes, key messages, and intended audience. Once these objectives and content scope had been agreed upon I undertook additional research into the subject matter to develop the final content. As part of this client-adviser relationship the final content was finessed through a series of focussed interviews with CAMS to incorporate popular science aspects with the scientific facts, adhering to their requirements of specific and accurate content, producing a coherent narrative of the science behind antimatter, under the five themes outlined earlier.

As the adviser I oversaw the development of this project guided by industry recommendations and science communication theory. I undertook the writing of the label copy, selecting, sourcing and negotiating the copyright agreements for the images, negotiating with the relevant stakeholders over content, style and imagery, working with the graphic designer to create the artwork, editing the final copy and seeking final approval from all stakeholders on the copy prior to production.

In the role of project adviser I regularly negotiated with the stakeholders to ensure best practice was adhered to where possible. The final product surpassed the initial objectives of the project, fulfilling CAMS' original aims pertaining to the scope, style, language, design, scientific content and imagery used to create the display. Stakeholder negotiations were a significant part of this project due to their conflicting requirements. Other constraints of the project that were compensated for in the exhibit design, through the use of a one-way communication model, included the restricted availability of the exhibition space, limited budget, and complexities of the subject matter and level of detail in the content required in the exhibit by the stakeholders.

Working on an outreach project for an ARC Centre of Excellence provided me with a unique experience: fulfilling a government mandate from a funding body; working across the cultural boundaries of academia, the science communication industry, with public sector with ANSTO and Questacon and with private industry with Siemens; satisfying their individual requirements. In working across these different sectors, from multinational companies down to individual service providers, liaising with vast demographics of collaborators enabled me to develop skills in being tactful, considerate, timely and respective to the stakeholders' needs essential for a successful adviser.

APPENDIX D

Centre for Antimatter-Matter Studies project panels – 'Antimatter – does it Matter?'

APPENDIX E

Invitation to participate in research study

Day DD Month YYYY

Name
1234 Street Ave

Tegan Donald
PhD Candidate

Australian National Centre for the Public Awareness of Science

T: +61 2 6125 2510
E tegan.donald@anu.edu.au

Canberra ACT 0200 Australia
www.anu.edu.au

CRICOS Provider No. 00120C

Dear [to be personalised]

Invitation to Participate in Research Study
'A Scientifically Engaged Australia'

I am undertaking a research study as part of a Doctor of Philosophy degree at The Australian National University, through the Australian National Centre for Public Awareness of Science, and write to request an interview with you.

In 2010 the Commonwealth Government launched its 'Inspiring Australia' program described as 'a national strategy for engagement with the sciences'. It was the first national government-level program specifically established to further the aims of science communication. The aim of this study is to explore what 'a scientifically engaged Australia' might look like.

I am asking a small group of leaders and pioneers in this field to participate, and would very much appreciate the opportunity to include you in this research study.

The aim of this research is to:

- provide clarity on what 'science engagement' entails, in terms of both processes and outcomes;
- provide clarity for science communication practitioners, policy-makers and researchers;
- contribute towards informing public policy in relation to setting Australian science communication agendas; and
- result in the publication of a PhD thesis at The Australian National University and, potentially, associated journal papers.

Your involvement would constitute participating in a half-hour recorded interview at a time and place convenient to you; I anticipate seeking an appointment with you in late October or November this year. By participating in this study you will be personally identifiable, and your comments attributable. You will be able to review, edit and approve the interview transcript. The interview recording will not be published.

This research operates under the research ethics protocol of the University (approval enclosed) and is not funded by any external sources. I would like to note that should you agree to an interview, you may withdraw from the study any time up until the final analysis of the results. Participation is strictly voluntary, and I am unable to offer a payment for participating.

I would be pleased to provide you with a copy of the research report summary when it becomes available.

Thank you for your consideration; your participation would provide invaluable information for this research. If you are interested in participating in this research study, or have any questions please do not hesitate to contact me on (02) 6125 2510 or Tegan.Donald@anu.edu.au.

Kind regards

Tegan Donald

Dr Lindy Orthia (Supervisor)
E: Lindy.Orthia@anu.edu.au
T: 02 6125 6148
Australian National Centre for the Public Awareness of Science
Physics Link Building 38a, Science Road
The Australian National University
Canberra ACT 0200

APPENDIX F

Information sheet and consent form

Research Study Information Sheet and Consent Form
'A Scientifically Engaged Australia'

Thank you for agreeing to participate in this research study. This study is being undertaken as part of a Doctor of Philosophy degree at The Australian National University, through the Australian National Centre for Public Awareness of Science. The intent of this study is to explore what 'a scientifically engaged Australia' might look like.

The results of this study will be published as a PhD thesis, and potentially associated journal papers. This study is not funded by any external sources. It is expected that this research study will take up-to half an hour.

The research objective is to explore the aims of creating 'a scientifically engaged Australia'.
The outcomes of this research will:

- Provide clarity on what 'science engagement entails, in terms of both processes and outcomes.
- Provide clarity for science communication practitioners, policy-makers and researchers.
- Contribute towards informing public policy in relation to setting Australian science communication agendas.
- Result in the publication of a PhD thesis at The Australian National University.

By participating in this study you will be personally identifiable and any comments you make will be attributed to you. You will be able to review, edit and approve the interview transcript.
The data collected from this study will be treated as confidential accessed only by the research team until formal publication of the study. Once the project is completed, all hard copy and electronic documents will be stored at the Australian National Centre for the Public Awareness of Science, in a designated locked cabinet within a locked room, for five years after any publication arising from the research

Participation is strictly voluntary, and no payments will be made in exchange for participating.
You will be provided with a copy of the research report summary.

By giving your consent to participate in the this study you are agreeing that you have had the project explained in sufficient detail by the researcher and have read and understand the information provided and agree to the terms outlined on this sheet.

This research operates under the research ethics protocol of the University and the ACT Department of Education and Training, and any questions or complaints can be forwarded to:
Human Ethics Officer
Human Research Ethics Committee
The Australian National University
T: 02 6125 3427 E: Human.Ethics@anu.edu.au

Thank you for your participation in this research study. If you have any further questions please do not hesitate to contact me.

Kind regards

Tegan Donald
E: Tegan.Donald@anu.edu.au
T: 02 6125 2510

Dr Lindy Orthia (Supervisor)
E: Lindy.Orthia@anu.edu.au
T: 02 6125 6148

Australian National Centre for the Public Awareness of Science
Physics Link Building 38a, Science Road
The Australian National University
Canberra ACT 0200
The Australian National University
Canberra ACT 0200

Research Study Consent Form
'A Scientifically Engaged Australia'

1. I …………………………………………………………..…………..(please print name) give my consent to take part in the abovementioned research study. I have read the Information Sheet provided, and understand its contents. I have had the research project explained to my satisfaction by the researcher. My consent is freely given.

2. I understand that from the information gained during this research project I will be identifiable where any comments I make will be attributed to me and can be published.

3. I consent to having this interview be recorded and transcribed. I understand that I will be given the opportunity to review and edit the transcription.

4. I understand that the data collected will be kept confidential so far as the law allows. This form and all other data collected throughout the duration of the study will be stored in a locked office at The Australian National University, and electronic data on password protected computer devices.

5. I understand that participation may be withdrawn from the research project up until the final analysis of the results, without providing a reason, and that this will have no adverse consequences. If participation is withdrawn, then the information provided will not be used.

6. I understand participation is strictly voluntary, and no payments will be made for it.

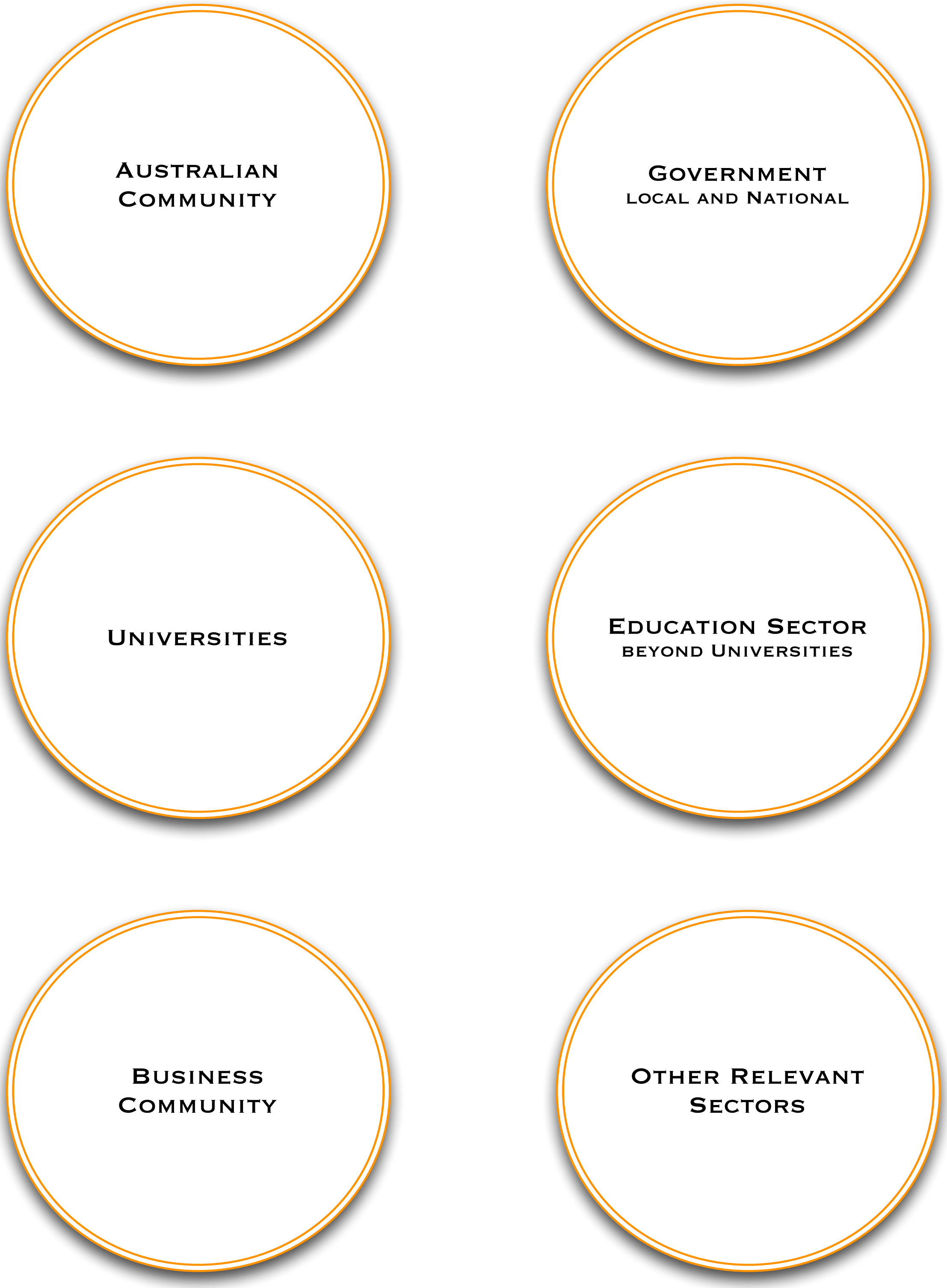
Signed:

Date:

APPENDIX G

Supplementary information for interview questions – diagram of different sectors

What would a scientifically engaged Australia look like?



Through what mechanisms?

Australian Community

Government
local and National

Universities

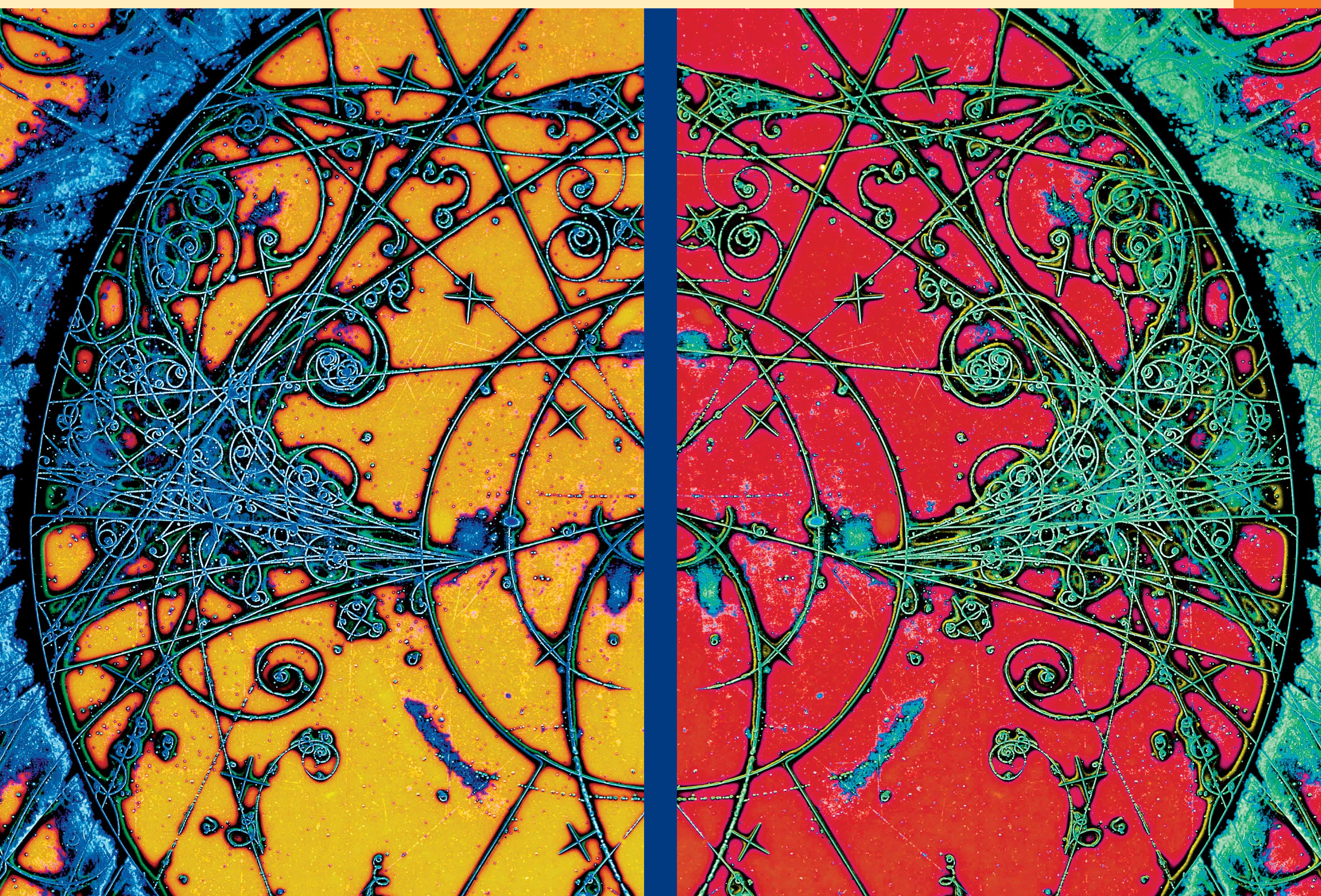
Education Sector
beyond Universities

Business Community

Other Relevant Sectors

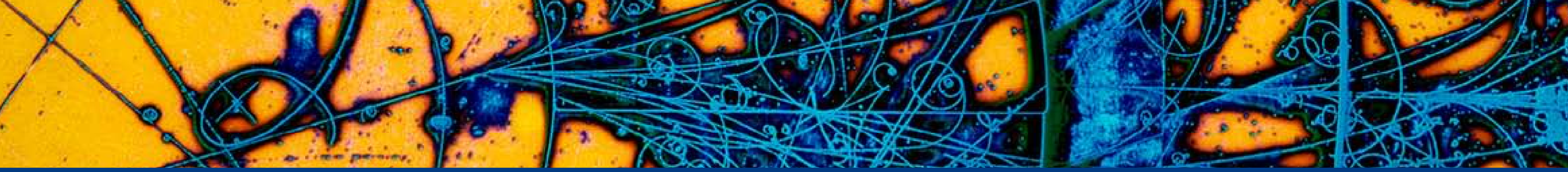
Antimatter — does it Matter?

Could there be an anti-you living on an anti-Earth?



ARC Centre of Excellence for Antimatter-Matter Studies

The Australian Research Council Centre of Excellence for Antimatter-Matter Studies (CAMS)



Antimatter & Matter

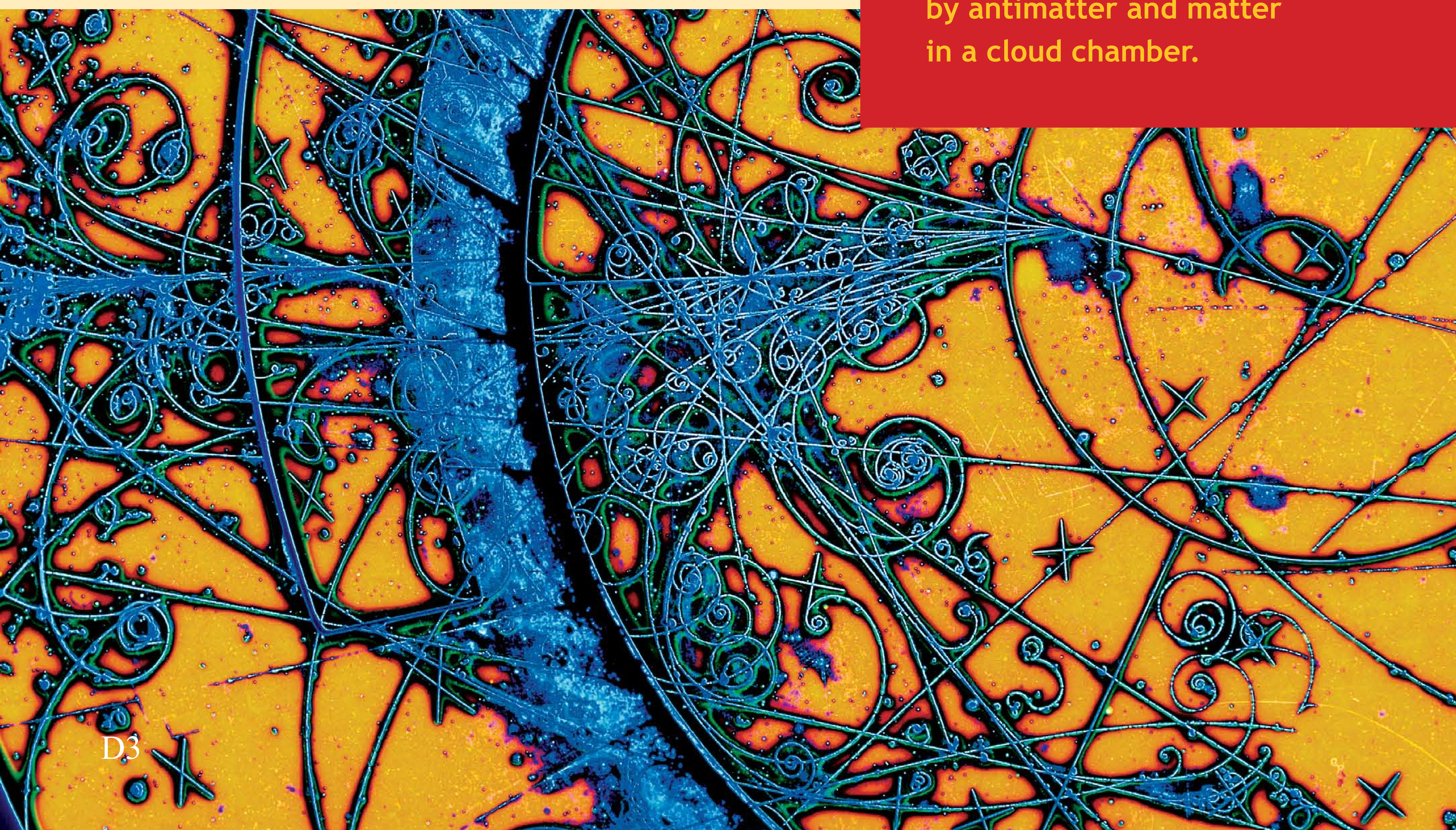
Antimatter is not just a creation of science fiction —it occurs naturally throughout the Universe.

Here in Australia, antimatter is created and used in many places, from hospitals to science laboratories.

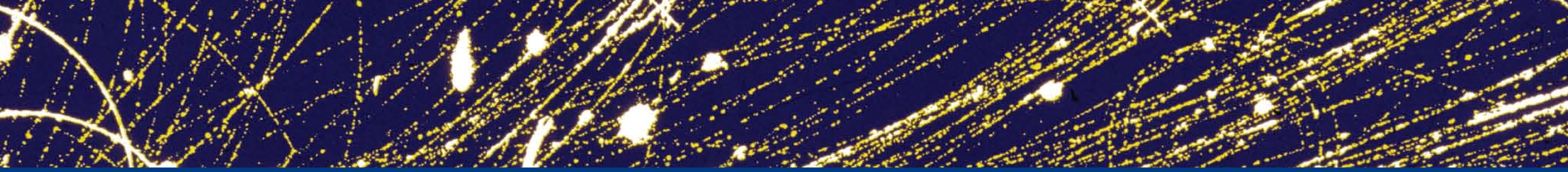
Antimatter is not only created and studied by scientists at the ARC Centre of Excellence for Antimatter-Matter Studies (CAMS), it is also used in many practical applications from materials engineering to medicine.

Do you think antimatter has ever touched your life or the life of someone you know?

Image courtesy of CERN / Science Photo Library



This image is not an artist's creation, nor is it a mathematical fractal. This image has been created by antimatter and matter in a cloud chamber.



What is Matter?

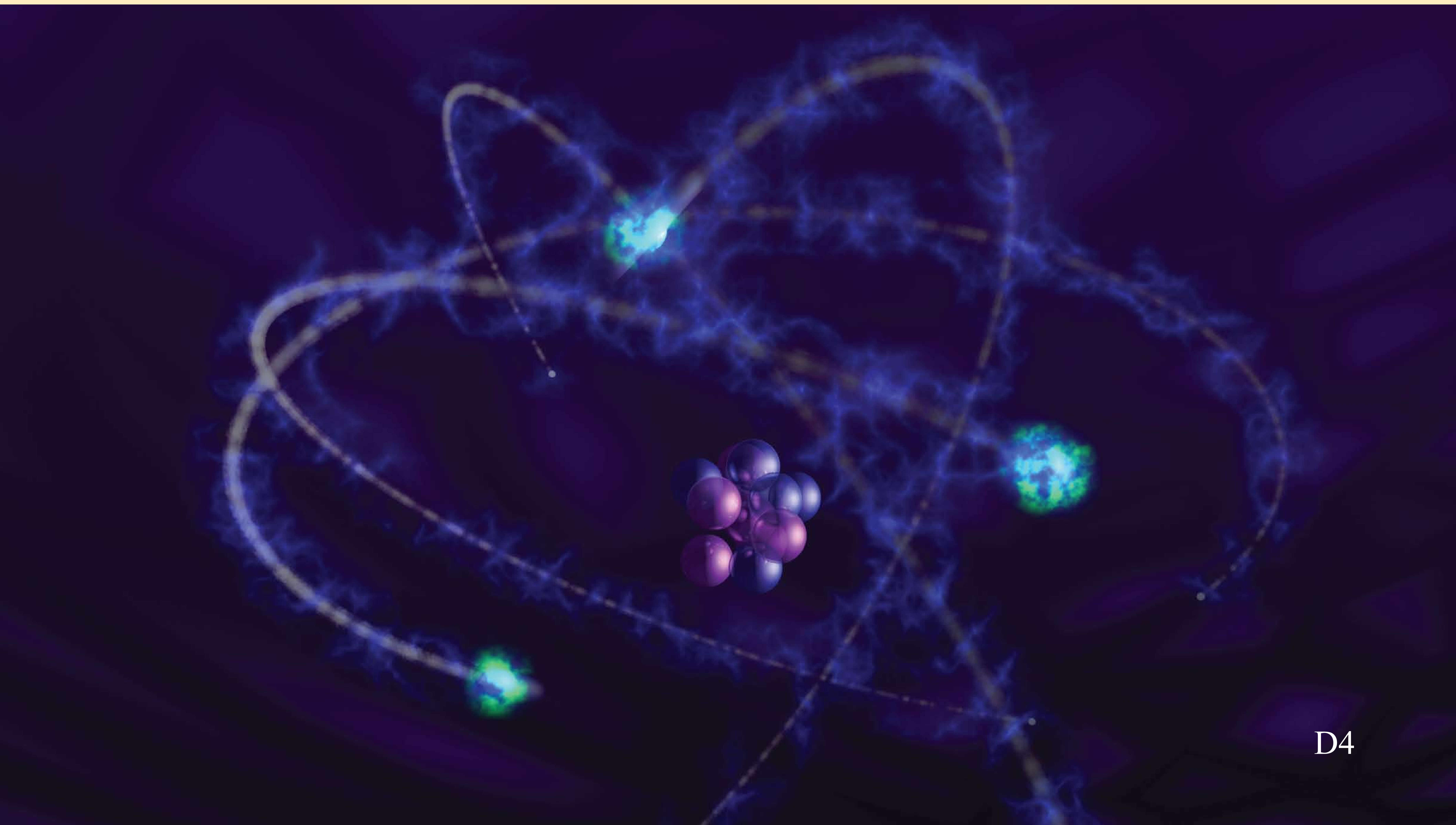
Everything that exists is made up of matter: you, the planet, your house, your dog, your Aunty Maureen and the stars.

The building blocks of matter are the particles inside *atoms*. If we look deep inside the structure of atoms then we find *protons*, *neutrons* and *electrons*.

Mathematical *equations* describe the behaviour of the atom. It is these equations that have *unlocked the mystery* of antimatter.

Everything that exists is made of matter. Matter is made of atoms. Inside atoms you will find protons and neutrons in the centre, and electrons orbiting around them.

Image courtesy of CERN



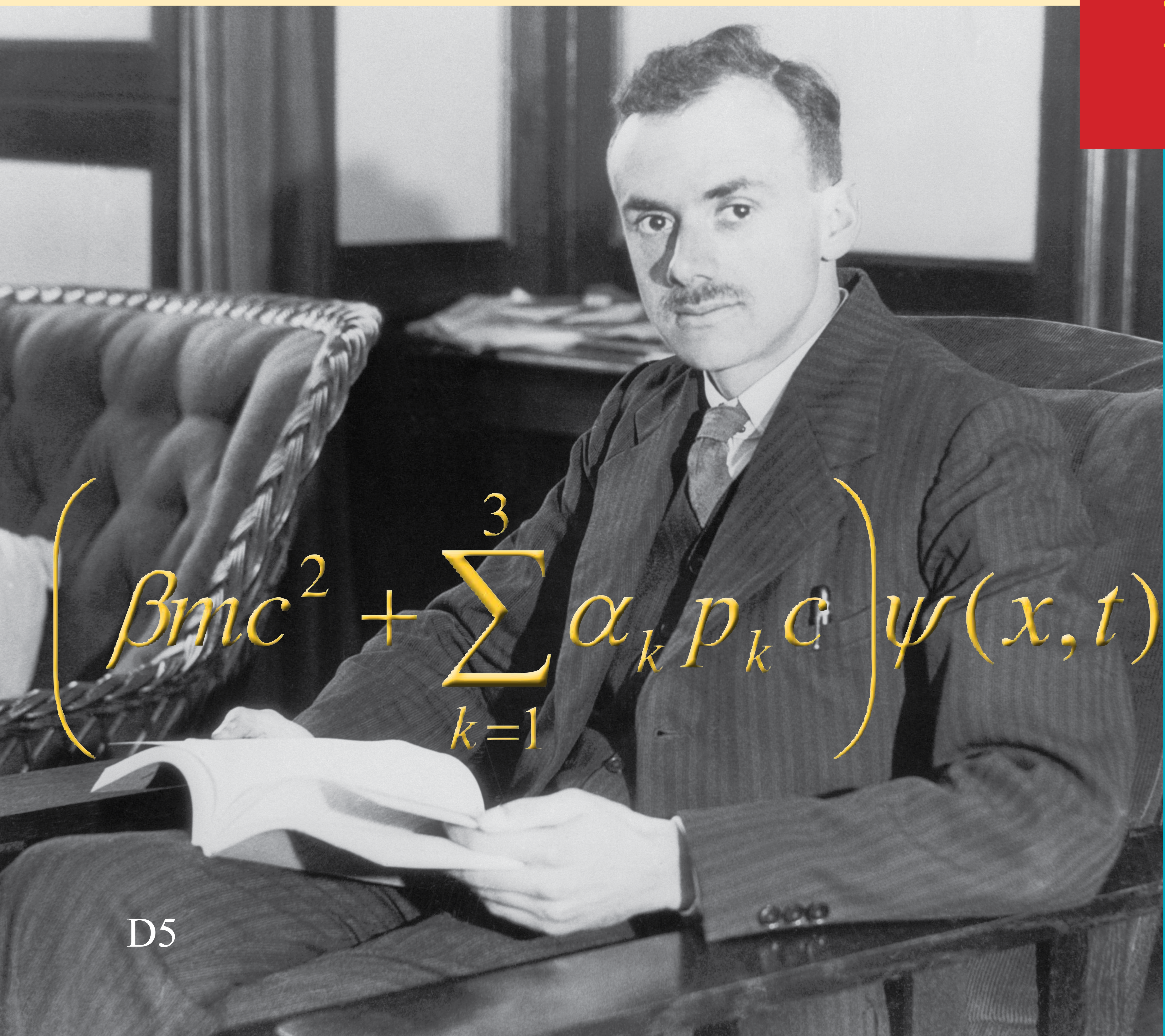
A Surprising Solution

Paul Dirac, 1902-1984, was a British theoretical physicist who made significant contributions to the early development of *quantum mechanics*—the best theory we have so far for how the Universe works.

In *1928* Dirac was studying the equations which describe the behaviour of the electrons in an atom. When he solved these equations he found both *negative and positive energy solutions*. With profound insight Dirac realised that these *negative energy* solutions *predicted the existence* of a positive electron—*antimatter*!

Paul Dirac, a British physicist, first proposed the existence of antimatter in 1928. Dirac solved the mathematical equations that describe the behaviour of the electron and found a negative energy solution. With this negative solution and a flash of insight he predicted the existence of antimatter.

Image courtesy of Corbis



$$\left(\beta mc^2 + \sum_{k=1}^{3} \alpha_k p_k c\right)\psi(x,t) = i\hbar \frac{\partial \psi}{\partial t}(x,t)$$

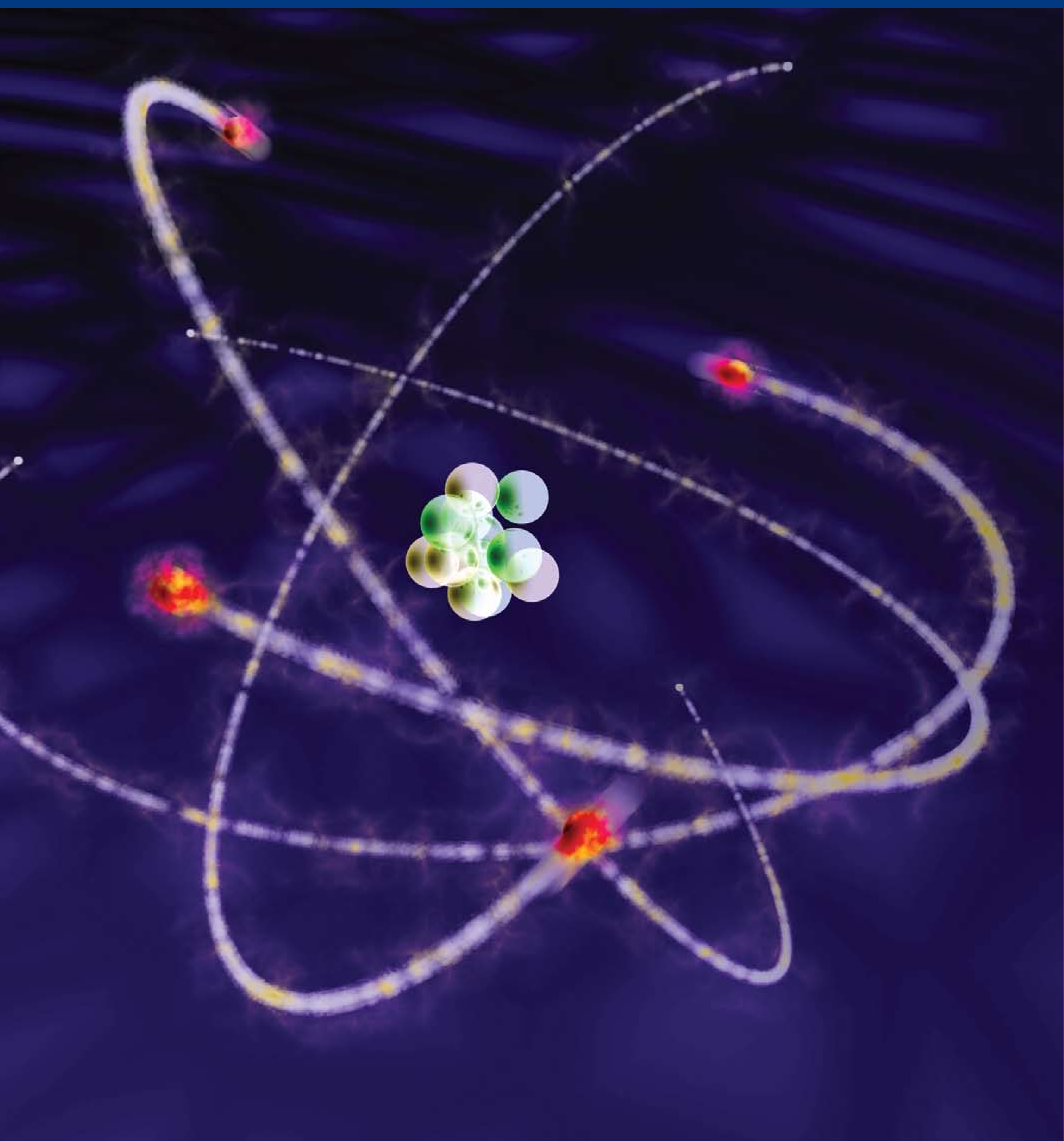
What is Antimatter?

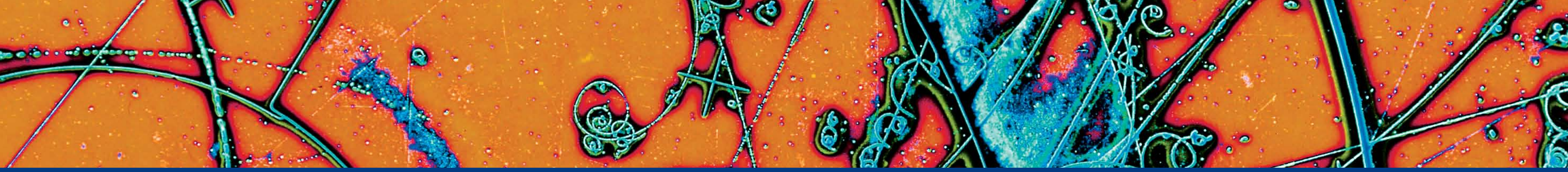
Following Paul Dirac's discovery of antimatter in 1928 we now know that, for almost every matter particle, there exists a *corresponding antiparticle*. It is these antiparticles that collectively we know as *antimatter*.

Antiparticles have properties that are similar, but also *opposite*, to their corresponding matter particles. They possess the *same mass* but the *opposite charge*.

The most common type of antimatter in the Universe is the positron—the positive electron.

For every particle there exists a corresponding antiparticle. Antimatter particles have the same mass but opposite charge to matter particles.

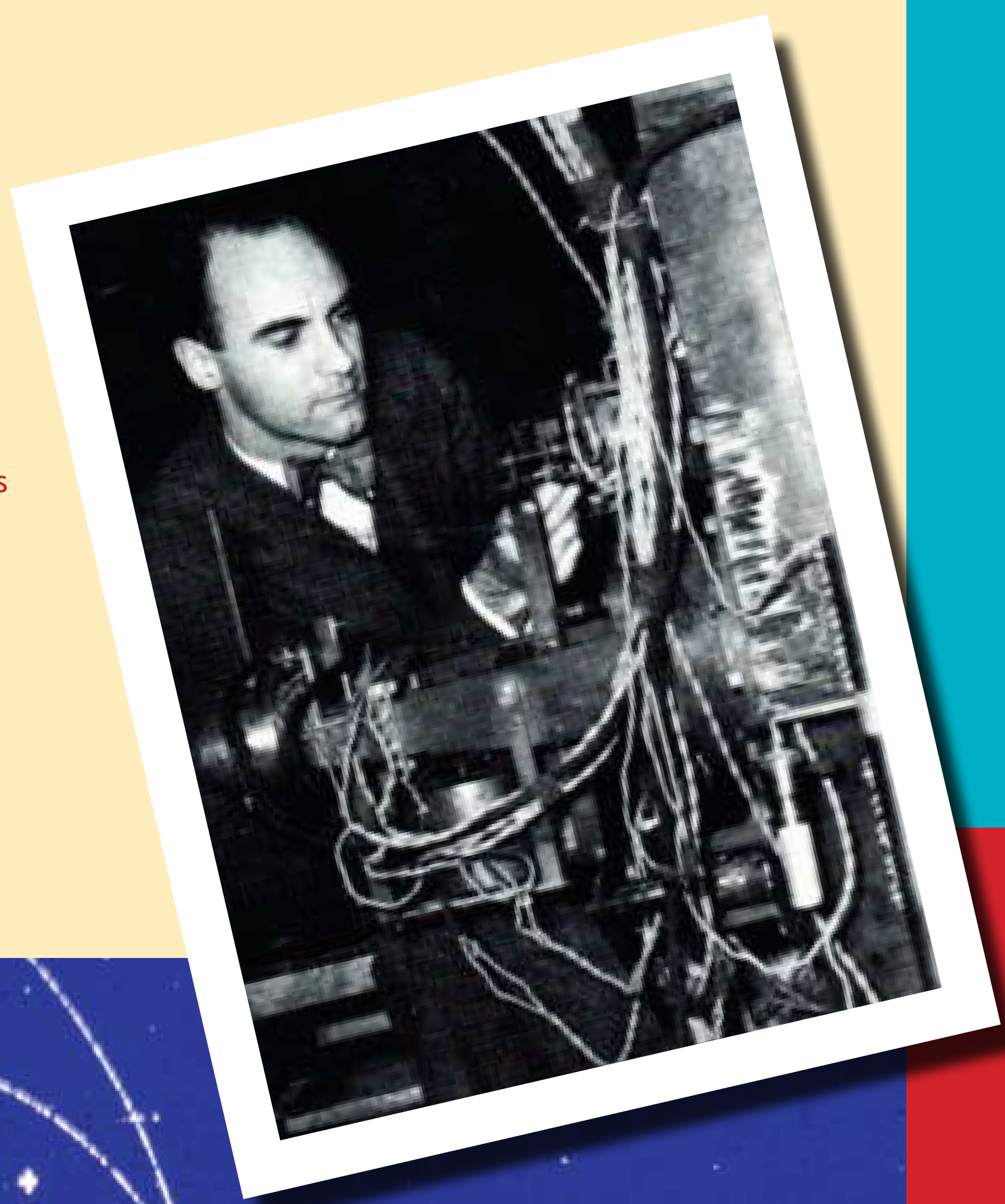




First 'Sighting' of Antimatter!

Carl D Anderson, 1905-1991, was an American experimental physicist and engineer.

In *1932*, four years after Dirac's mathematical discovery, Anderson was studying the behaviour of sub-atomic particles (electrons, protons and neutrons) in a cloud chamber.



Carl Anderson
Image courtesy of Corbis

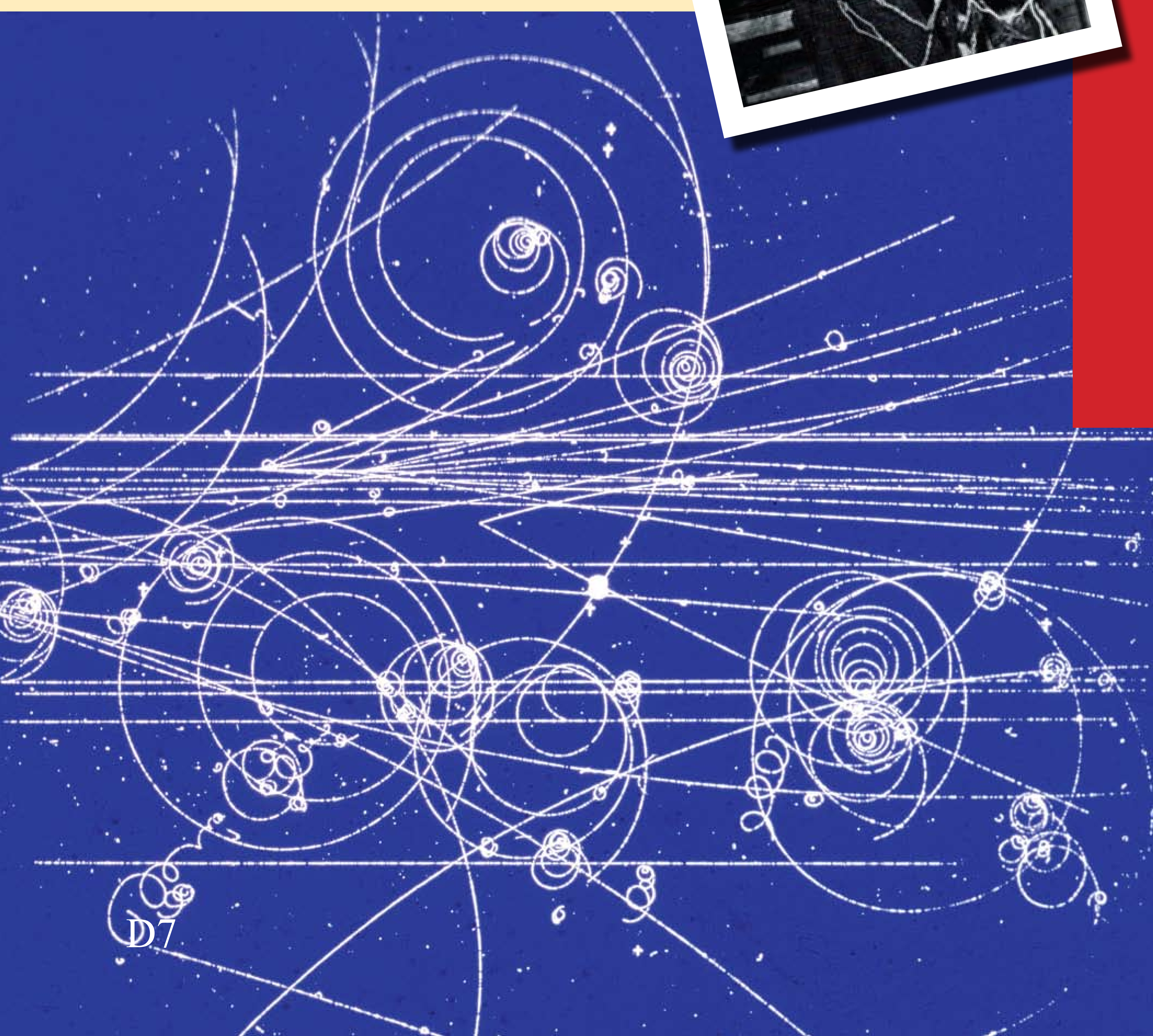
Cloud chambers

Cloud chambers are devices which were used to ***detect*** sub-atomic particles.

They are sealed environments that contain very cold water or alcohol vapour and a high magnetic field. When ***particles travel*** through the ***cloud vapour*** (mist) they leave ***tracks or paths*** behind in their wake. A bit like the vapour trails left behind by an aeroplane. The magnetic field has an effect on the different masses and charges of the particles causing them to spiral and spin in a particular way creating the ***different patterns***.

Each different type of particle makes its own ***unique track*** in the cloud vapour. By studying these tracks we can identify which particles were present.

Image courtesy of CERN



The lines you see here are the paths traced by sub-atomic particles in a cloud chamber. The magnetic field in the chamber causes the particles to spin and swirl according to their mass and charge.

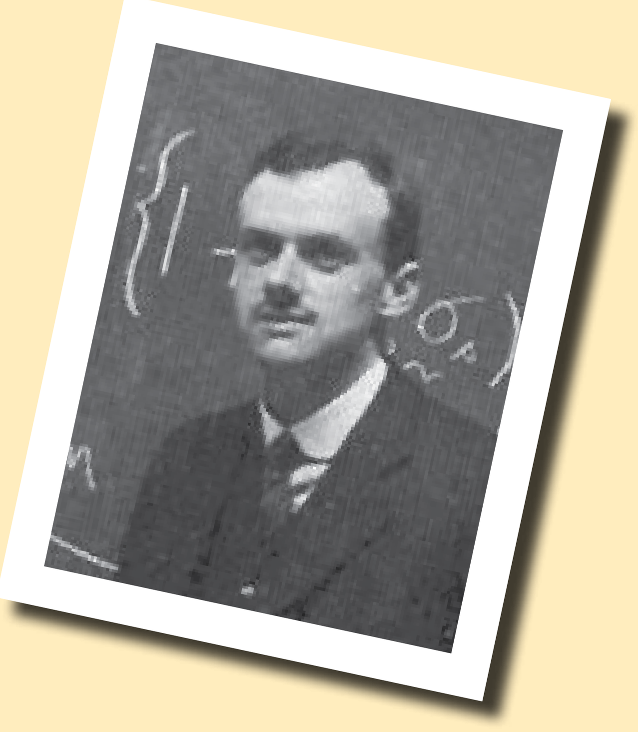
Big predictions

Carl Anderson was familiar with the tracks that electrons made in the vapour of the cloud chamber. So when he saw the same pattern, but one in which the particle was spinning in the *opposite* direction, Anderson knew that this particle had the *same mass as the electron but an opposite charge*. This was a positive electron—the *positron*.

It is this moment, when the positron was first observed, that marked the experimental discovery proving the existence of antimatter.

The positron (positive electron) was named by Anderson after its experimental discovery in 1932. The discovery of antimatter was so *unusual* because it was *mathematically predicted* four years earlier by Paul Dirac before being *experimentally verified* by Anderson.

Carl Anderson
Nobel Prize 1936
Image courtesy of Corbis



Paul Dirac
Nobel Prize 1933
Image courtesy of AIP Emilio Segrè Visual Archives

Over four years after both men's initial predictions, they both received the *Nobel Prize for Physics* for their work in proving the existence of antimatter.

In 1932, Carl Anderson, an American physicist, observed a pattern in a cloud chamber that swirled in the opposite direction to that made by an electron. The particle had the same mass but an opposite charge to an electron. This observation proved the existence of antimatter.

Antimatter here on Earth

Antimatter, in particular the positron, is used every day and not just in science laboratories.

Antimatter can be found in hospitals for use in Positron Emission Tomography (PET) scanners. It is also widely used as a probe into the structure of materials in nanotechnology and materials engineering.

To the best of our knowledge, the most common type of antimatter in the Universe is the positron (positive electron).

The positron is the basis for the majority of antimatter research at the ARC Centre of Excellence for Antimatter-Matter Studies (CAMS).

Antimatter is made:

- by particle accelerators
- through radioactive decay

The most common type of antimatter is the positive electron (positron). It is created in particle accelerators or through radioactive decay for use in medicine and research.

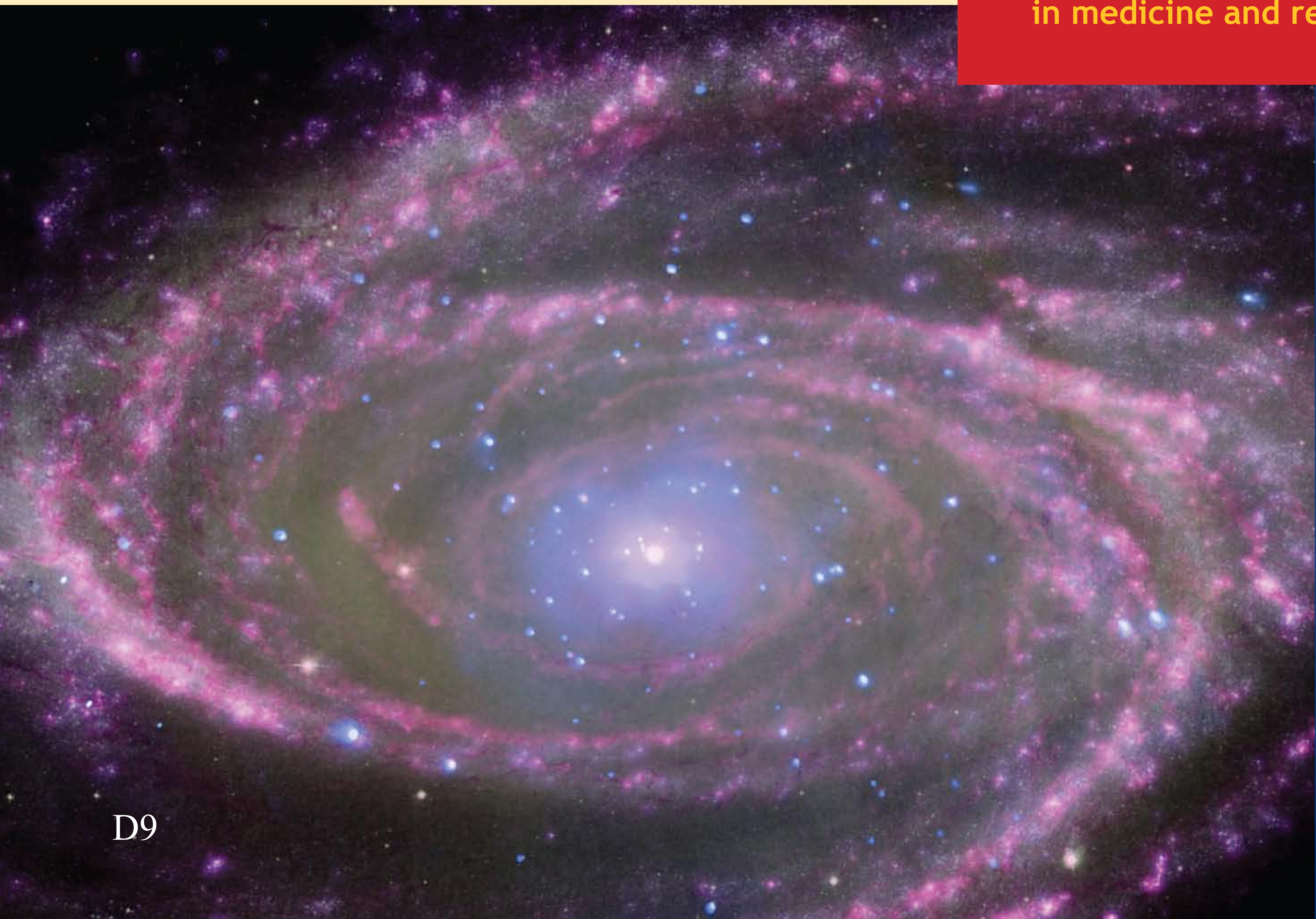


Image Credit: X-ray: NASA/CXC/Wisconsin/D.Pooley & CfA/A.Zezas; Optical: NASA/ESA/CfA/A. Zezas; UV: NASA/JPL-Caltech/CfA/J.Huchra et al.; IR: NASA/JPL-Caltech/CfA

How to make Antimatter

Radioactive decay

In Australia at the ARC Centre of Excellence for Antimatter-Matter Studies (CAMS) we create antimatter through the radioactive decay of the sodium-22 isotope, an unstable atom.

Radioactive decay is the *spontaneous* process where an unstable atom *loses energy* to become stable by emitting radiation in the form of *high energy particles*.

Some of these emitted particles are *antimatter*, and in particular positrons. The decay of sodium-22 produces neon-22, a positron (e^+), a gamma ray (γ) and a neutrino (ν).

$$^{22}Na \rightarrow {}^{22}Ne + e^+ + \gamma + \nu$$

Particle accelerator

Antimatter (positrons) can also be made in extremely large particle accelerators such as the one at the European Organisation for Nuclear Research (CERN). The particle accelerator at CERN is hidden deep underground in a circular tunnel with a 27 km circumference.

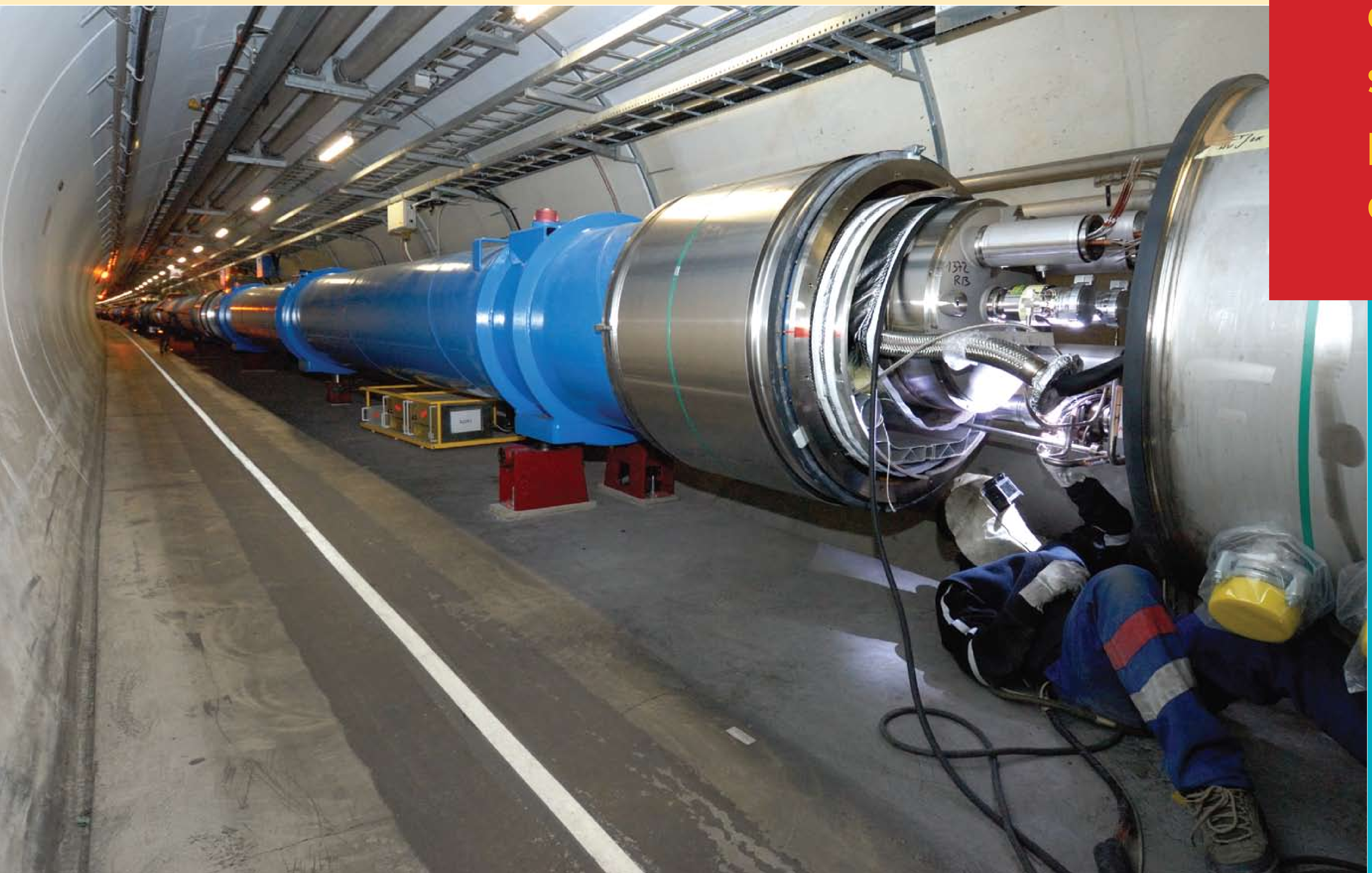
A particle accelerator uses electric fields to propel particles at *high speeds* to *collide* with targets. When the particles collide, the impact *sprays off* many of the smaller particles that make up atoms, as well as a small amount of *antimatter*. This antimatter can be captured and studied.

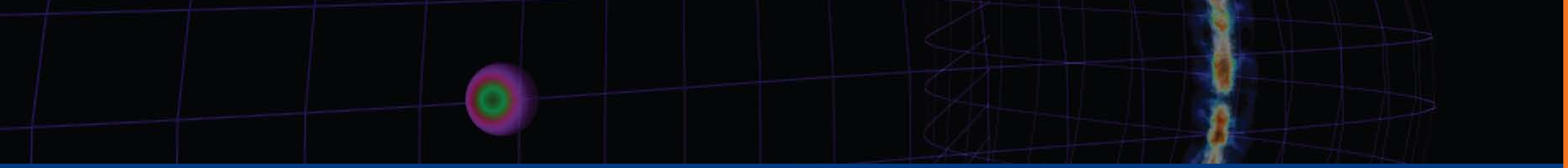
Cyclotrons

Cyclotrons are a *smaller* version of the CERN accelerator. Cyclotrons are located near most major *hospitals in Australia* and are used to make nuclear *medicines* and antimatter (positron) emitting isotopes.

Antimatter is made through radioactive decay, or in particle accelerators by colliding particles at high speed, causing sub-atomic particles and small amounts of antimatter to spray off.

Images courtesy of CERN





Anti-atoms

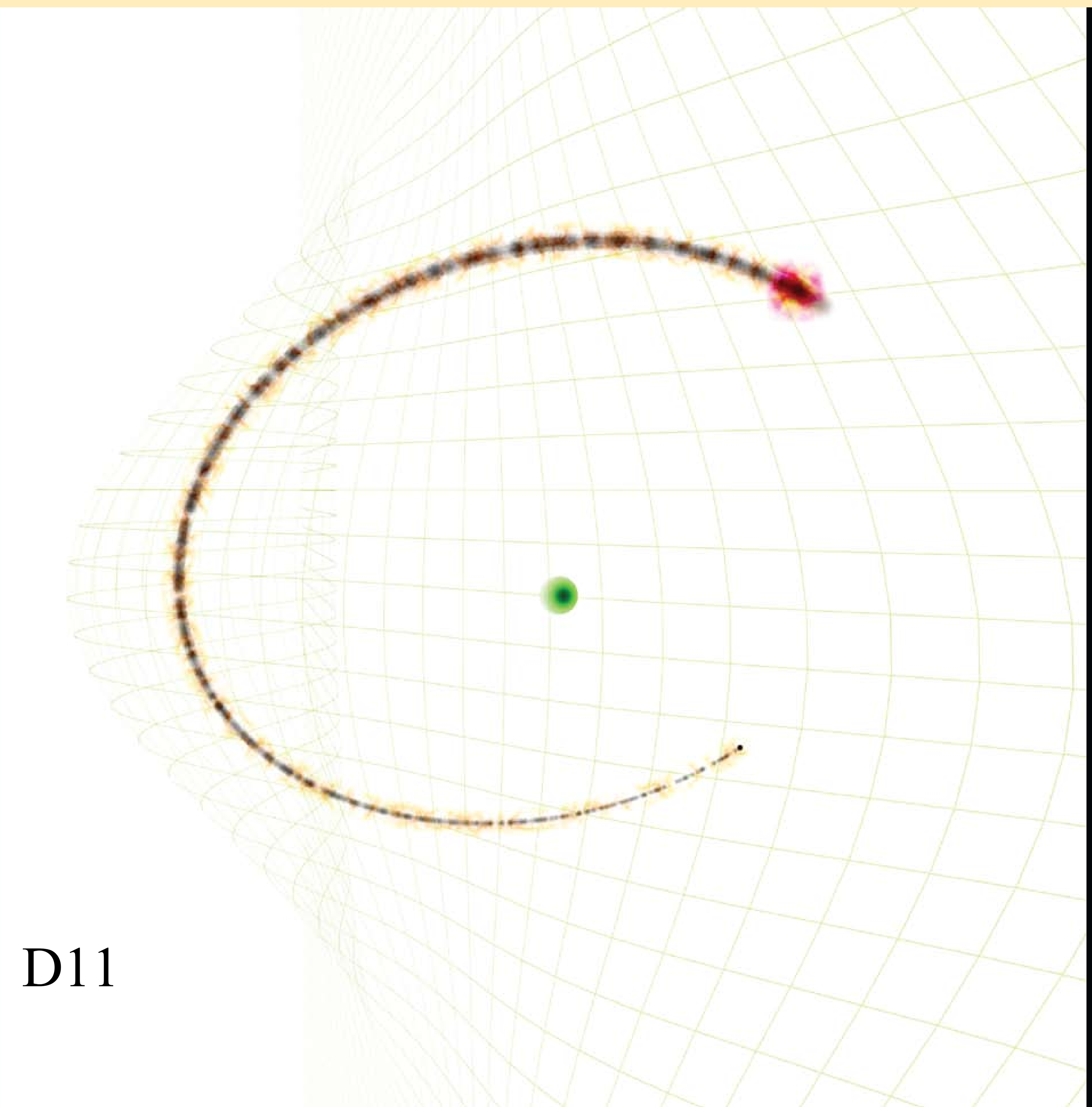
In *1995* scientists at CERN, the European Organisation for Nuclear Research, made the first anti-atom, anti-hydrogen, which is the simplest of all the *anti-atoms*.

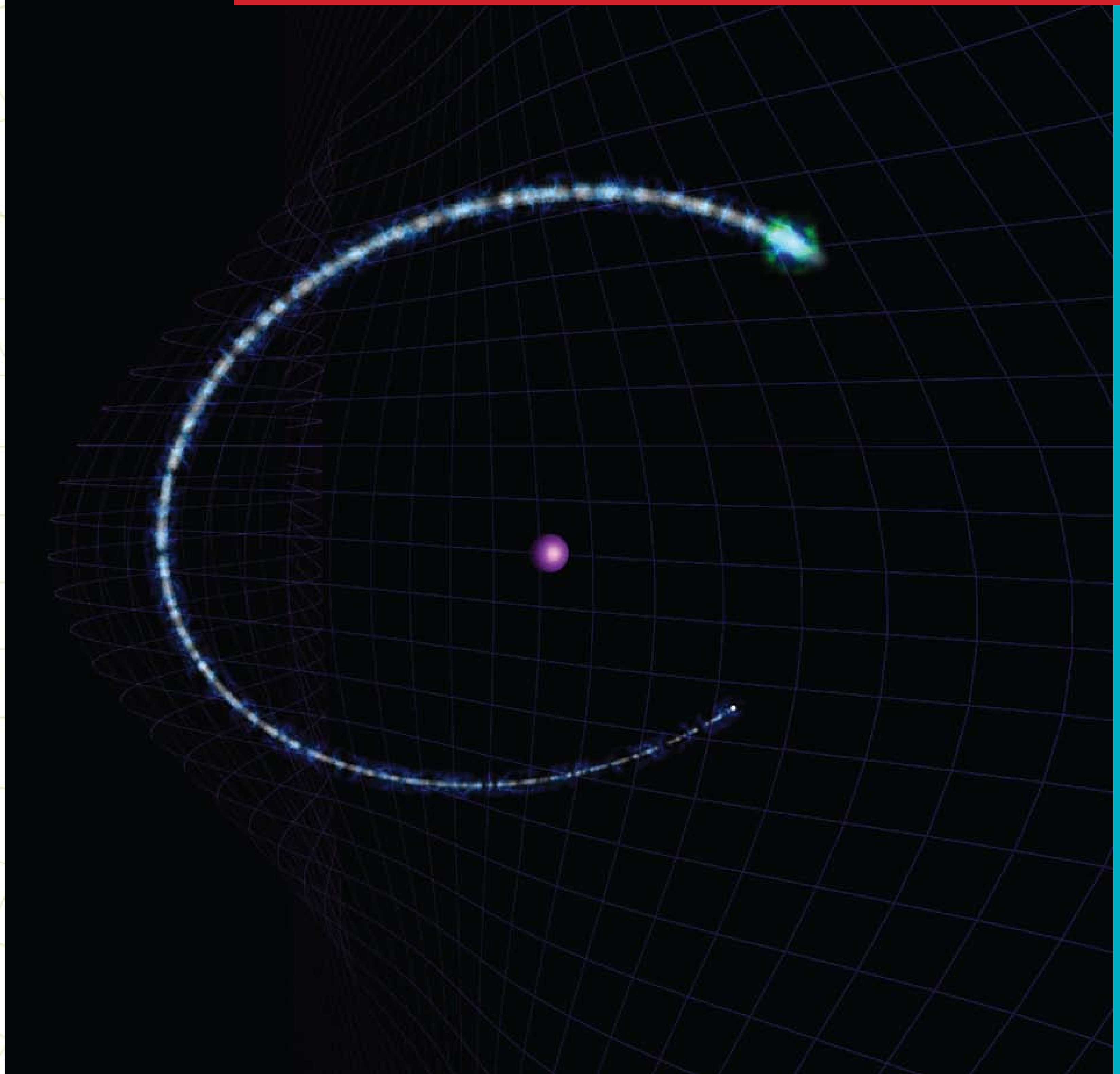
Normal *hydrogen* is made up of a *proton* (positive charge) and an *electron* (negative charge).

Anti-hydrogen is made up of an *anti-proton* (negative charge) and a *positron* (positive charge).

Now that we can produce anti-hydrogen, scientists are studying it to see if and how its *behaviour* differs from real-hydrogen.

Anti-hydrogen was first created in 1995 at CERN. An anti-hydrogen atom is made by combining an anti-proton with an anti-electron (positron).





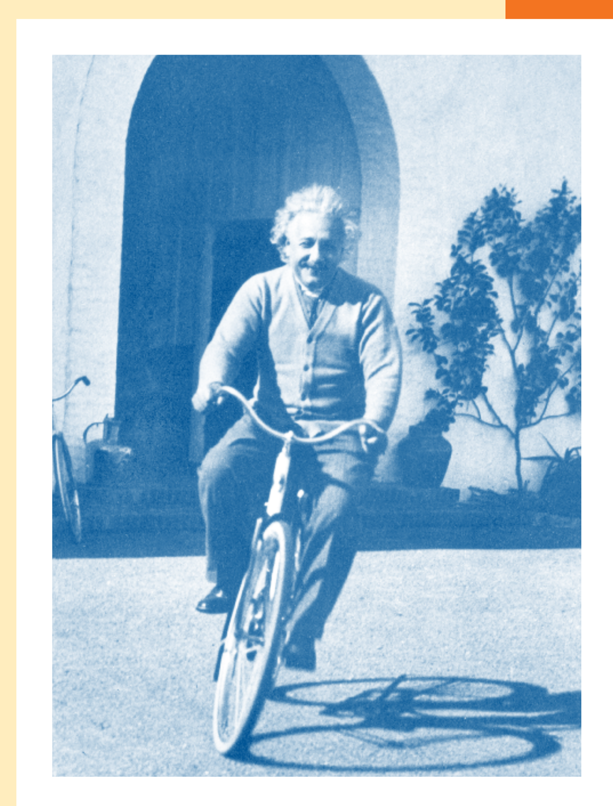
Energetic Annihilation

Antimatter particles such as positrons need to be treated with great care. When a particle comes into contact with its antiparticle...they both *annihilate!*

In the annihilation process the particles *release* their combined *mass* as *energy*. In the case of positron and electron annihilation, this occurs by releasing two gamma rays in opposite directions.

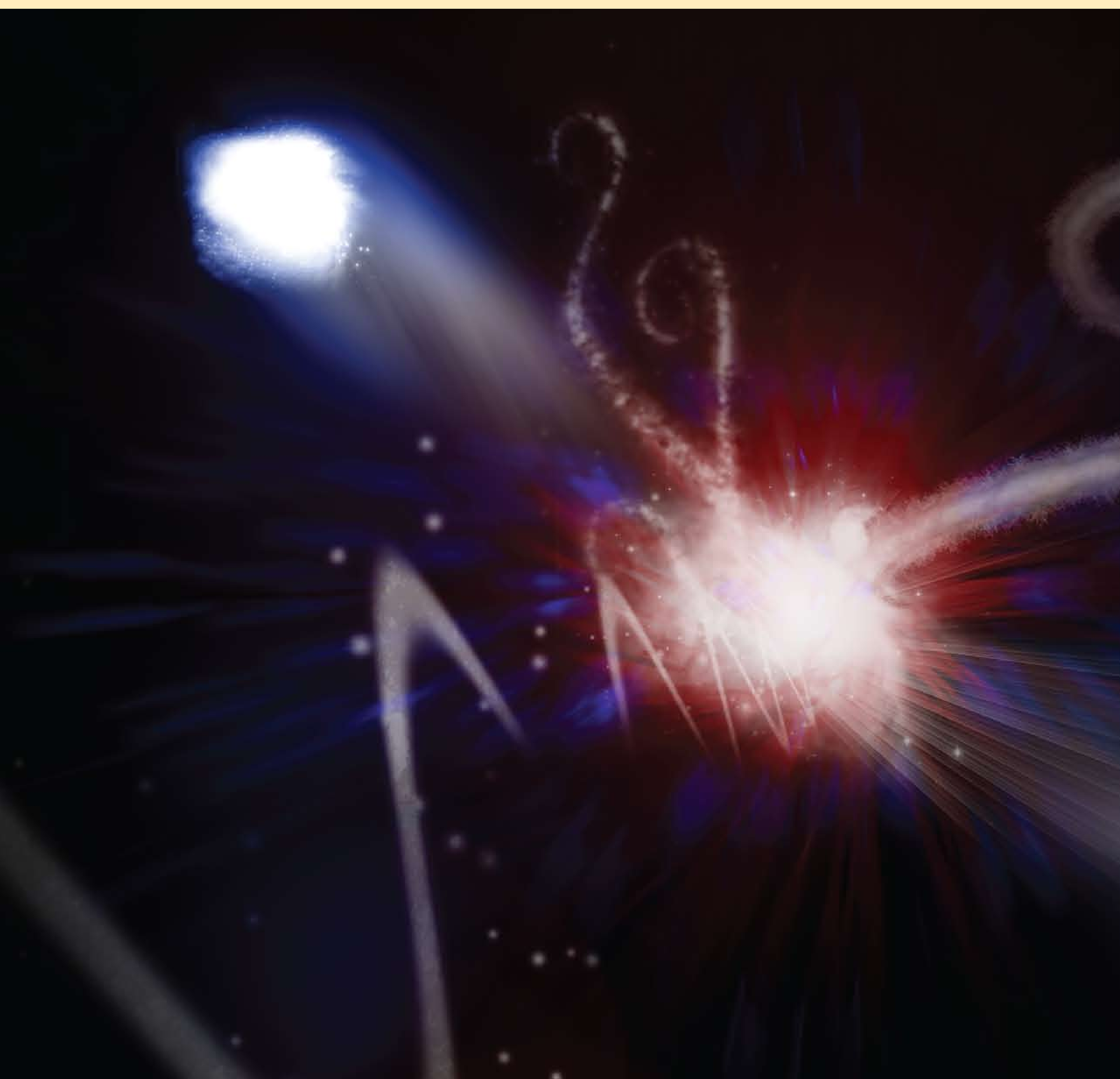
Albert Einstein showed that energy and mass are interchangeable by his equation

$$E = mc^2$$



So when two particles like the electron and its antiparticle, the positron, come into contact with one another they annihilate and, by Einstein's equation, they *transform their mass* into energy, releasing two gamma rays in opposite directions!

Image (above and below) courtesy of Teon Harasymiv
Image (top right) courtesy of the Hebrew University of Jerusalem



This artist's impression illustrates what happens when an antiparticle comes into contact with its real matter particle—they both annihilate! Einstein's energy equation $E = mc^2$ describes the process of annihilation. As they collide, the mass of both particles is transformed into a burst of energy.

Keeping it safe

Antimatter—you can't keep it in a box.

Once we have made our antimatter (positrons) either by radioactive decay or from a particle accelerator, we need to be able to *store* them for later use.

We trap the positrons in a device which involves a combination of *magnetic and electric fields in a vacuum*.

The positrons are *suspended* in these magnetic and electric fields, keeping them away from anything they can annihilate with—such as the walls of the container. This antimatter (positron) isolation is a very *tricky process* to maintain.

To use antimatter in practical applications such as medicine and engineering, one single positron is not enough. So we *need* to be able to *safely store and transport many positrons* without them annihilating.

Antimatter must be handled with care — or else it annihilates! To store antimatter, it is trapped within magnetic and electric fields in metal chambers like the one seen here at CAMS' laboratories.

Image courtesy of the Australian National University

Myths, Misconceptions & Bigger Questions

When you think of antimatter the first thing that comes to mind may be science fiction images of Star Trek, Dr Who shows or Dan Brown's novel, 'Angels and Demons'.

Not all *science fiction* is fantasy.

Let's consider the possibilities of antimatter weapons, *unlock* the secrets of antimatter as an energy source, *explore* the science behind antimatter propulsion and *probe* the larger questions of "where has all the antimatter gone?"

Image courtesy of CBS Entertainment

Antimatter conjures up images from science fiction. However not all science fiction is fantasy.

Antimatter Weapons?

Are they realisable?

Is the plot of Dan Brown's 'Angels and Demons' realistic? Brown's villain stole antimatter from CERN to make an antimatter weapon.

If we take *1 gram of antimatter* and allow it to annihilate with *1 gram of matter* (2 grams in total), using $E = mc^2$

Energy = mass multiplied by the speed of light squared

$E = 2 \times 0.001$ kg x $(300\,000\,000 \text{ m/s})^2$ joules

$E \approx 2 \times 10^{14}$ joules

Which is roughly the energy equal to two atomic bombs!

There is plenty of matter around but how do we get 1 gram of antimatter ($\approx 10^{23}$ particles)?

The world record for the number of antimatter particles stored is currently about 10^9 particles and it takes about 20 minutes to achieve this.

So, to get 10^{23} antimatter particles, at the world record rate, it would take 10^{17} seconds — which is a *few billion years*!

So unless, you have a few billion years to wait, such antimatter weapons are *not achievable* with present technology.

Images courtesy of Centre d'Expérimentation du Pacifique/Pierre Joliveau

Powers of Ten

When you see numbers written as 10^{23}, this is scientific notation to make numbers smaller when written. It is used for very large and very small numbers. When doing sums and calculations, if we write the number out in full it takes up too much space and can make simple calculations quite confusing.

So, when we say 10^{23} (positive 23) we mean a 1 with 23 zeros after it or 100 000 000 000 000 000 000 000

It works just the same way in reverse. When we say 10^{-23} (negative 23) we mean a 1 but with 23 zeros in front of it or 0.000 000 000 000 000 000 000 01

Which do you think is easier to write? 10^{23} or 100 000 000 000 000 000 000 000?

Can antimatter be used as a weapon? Luckily, no! With present technology it would take a few billion years to create enough antimatter to use as a weapon.

Antimatter Energy?

Could antimatter be a source of fuel? Would it satisfy the world's energy requirements?

Unlike typical fuel sources antimatter *does not occur naturally in large deposits*, so we just cannot go out and dig some up. *We have to make it*.

The production of antimatter is either by radioactive decay or through large particle accelerators—it is *difficult, expensive and energy intensive*.

Even if the process of generating energy from antimatter-matter annihilation was 100% efficient then from Einstein's equation:

$$E = mc^2$$

Energy = mass multiplied by the speed of light squared

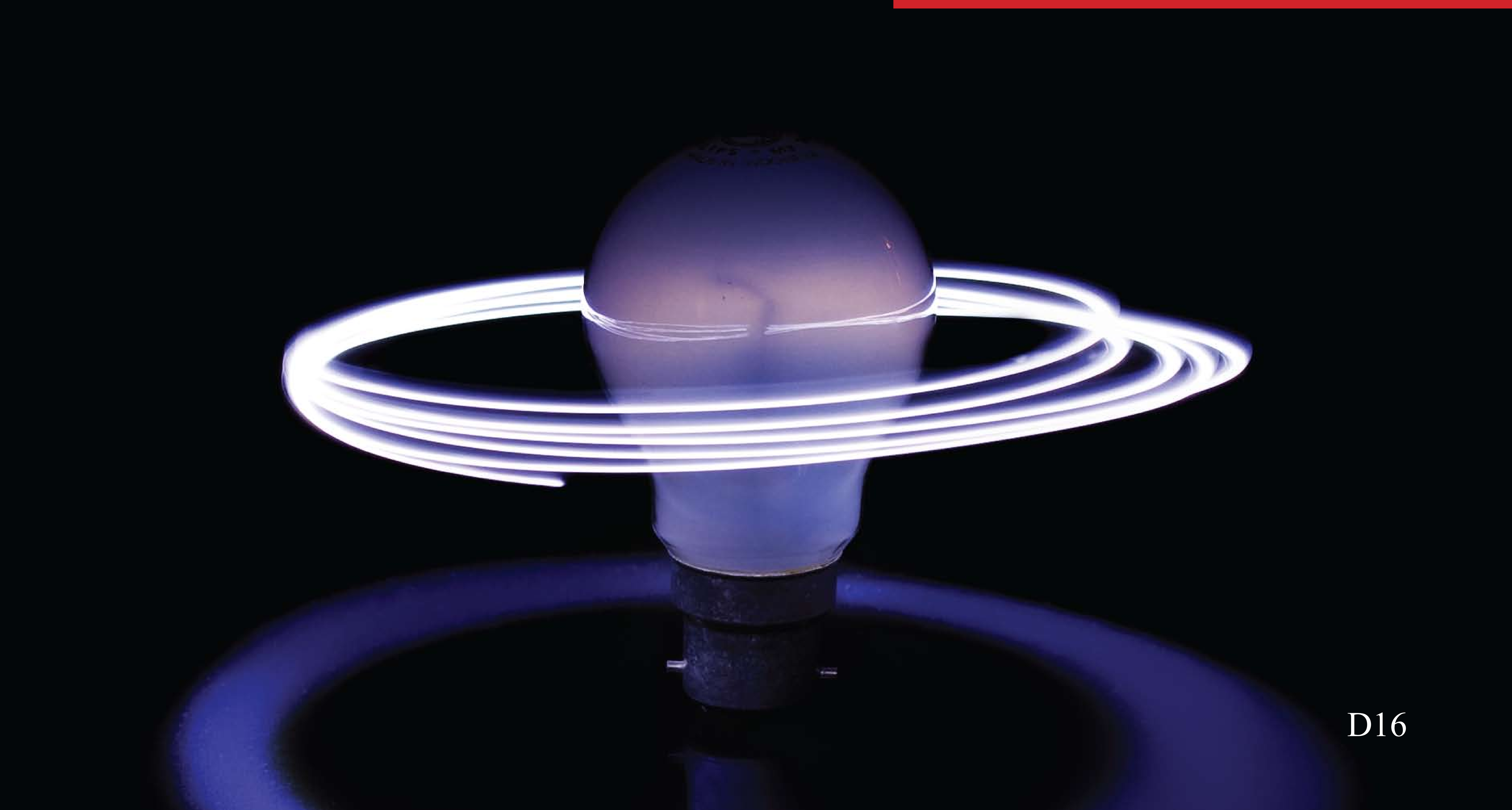
There *cannot be any net energy gain*. This is because we have already used up the energy that annihilation would produce by making the anti-particles in the first place.

If we sum up the *entire* amount of antimatter *ever produced* in the world to date it could only be used to power a standard light bulb for *maybe a few hours*!

So, in the absence of an antimatter deposit here on Earth—it seems very unlikely that antimatter will become an energy source.

Can antimatter be used as a source of power for our homes? While antimatter-matter annihilation is an attractive method to harvest energy—there is just not enough of it to power our homes.

Image courtesy of Teon Harasymiv



Antimatter Propulsion?

In science fiction the *Starship Enterprise* is powered by di-lithium crystals and an antimatter-matter reaction chamber. But how about our own spacecraft here on Earth?

Using antimatter as a source of domestic energy for our homes is *not a realistic* option due to the scale of the world's energy consumption. However, the antimatter annihilation process is an *attractive* method for propulsion to scientists, as it is a very high 'energy density' process. This means that the storage and output of energy from antimatter annihilation is much *more efficient* than the common chemical processes we use today.

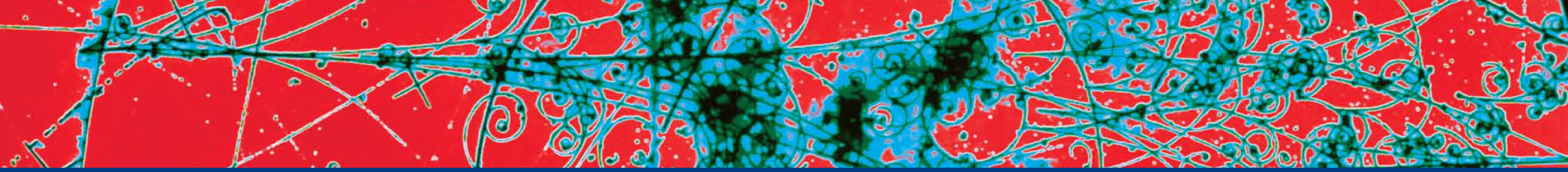
In fact, antimatter rocket fuel would have an 'energy density' of about *10 billion times* that of our chemical rockets. This means much *lighter fuel loads* for our rockets, perhaps enabling us to *travel further and faster* than ever before.

Antimatter propulsion is *currently being researched* at NASA and several other commercial enterprises.

So while antimatter is the main star in many science fiction stories there can be an element of truth behind the fiction—sometimes.

Can antimatter be used to power spacecraft, just like the Starship Enterprise? Antimatter is an attractive method of spacecraft propulsion and scientists around the world are currently investigating it.

Images courtesy of ESA - J. Huart ©



After the 'Big Bang'

At the time of the 'Big Bang' that created the Universe as we know it now, it is believed that matter and antimatter should have been *created in equal amounts*. But scientists have never been able to find enough antimatter in our Universe to match the amount of matter we have.

This highlights a possible violation (breakdown) in the symmetry laws of physics as we presently understand them.

The question "Where has all the antimatter gone?" has puzzled scientists since the discovery of antimatter in 1928 and is still a hot topic of research today.

There are currently investigations into these inconsistencies such as the:

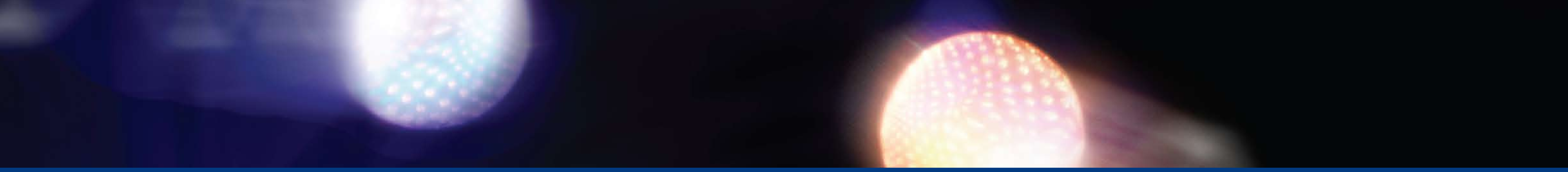
- search for antimatter galaxies —perhaps with an anti-you;
- search for antimatter hotspots in our Universe;
- search for the violation of the symmetry laws that govern physics.

Image courtesy of NASA and the Hubble Heritage Team (STScl)

"The best theory we have on how the Universe works also predicts that we shouldn't exist. It says that in the 'Big Bang', equal amounts of matter and antimatter were created. Since antimatter and matter annihilate each other when they come into contact, the Universe should have obliterated itself shortly after birth. That obviously means the best theory is wrong."

Dr Helen Quinn, Stanford Linear Accelerator Centre

Is there an anti-you? According to the symmetry laws of physics, matter and antimatter should have been created in equal amounts at the time of the 'Big Bang'. Scientists are currently searching for all this lost antimatter. Perhaps there is an anti-world to our own—it may even have an anti-you!



Everyday Antimatter

Antimatter is not only the star performer in many science fiction stories but it is also a useful tool in many practical applications such as medicine, nanotechnology and materials engineering. At the ARC Centre of Excellence for Antimatter-Matter Studies (CAMS) we create and use antimatter every day.

But what can antimatter show us that is so useful?

When antimatter and matter coexist

Antimatter and matter can ***get along***—for a short time at least. When an electron and its antiparticle, the positron, come into contact with one another they can form an exotic 'atom' called ***positronium***. The electron and its antiparticle, the positron, can coexist together in the form of positronium, where the two particles briefly orbit one another, ***before annihilating***.

It is positronium that lies at the heart of the research and applications of antimatter. Positronium ***delays*** the annihilation process —by 140 billionths of a second.

Images courtesy of Teon Harasymiv

Antimatter and matter can exist together as an exotic 'atom' called positronium —but only for a short time, before it annihilates!

It is this time delay caused by the 'lifetime' of positronium that can tell us so much about the surrounding environment in which it is formed.

Positronium and its lifetime is the key to many of the practical applications of antimatter.

What can Antimatter do for us?

How does antimatter tell us about a material's structure?

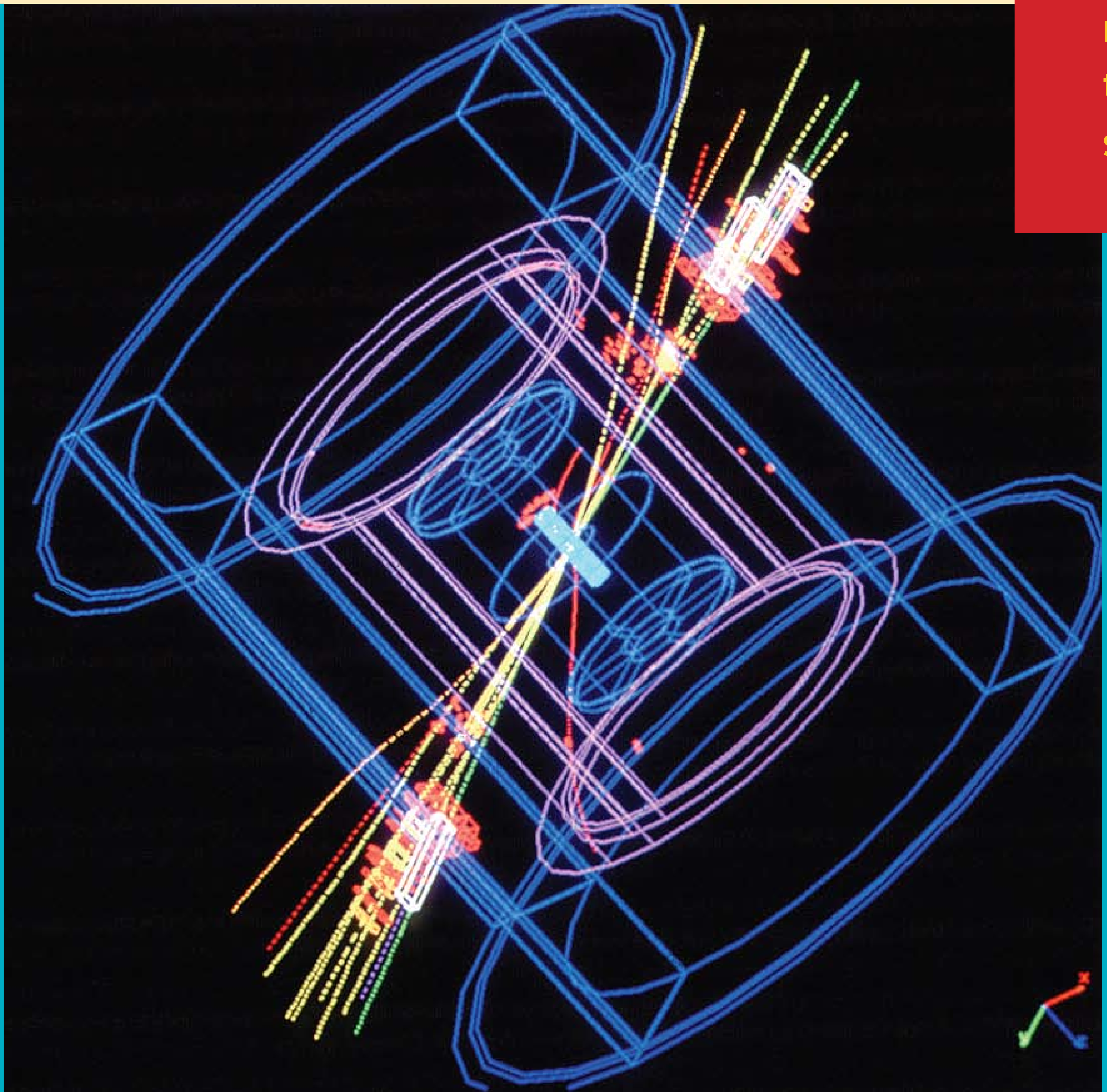
Antimatter (positrons) are introduced into the material to be investigated and it is the *survival time* of the positrons that can tell us a great deal about the material's structure.

Positrons can only annihilate with an electron. Positrons are *high energy* particles, whizzing around bumping into other particles losing energy with each collision. When they have lost enough energy the positrons are able to *entwine* themselves with an electron to form *Positronium* briefly, before annihilating.

Positronium can be used to *investigate* many different types of materials but it is best at investigating *soft materials*, with a low electron population (low electron density), such as plastics, membranes and materials with large open spaces such as *living organisms*—like you.

The time taken before Positronium, an 'exotic' atom of antimatter and matter, annihilates can tell us much about its surrounding environment.

Image courtesy of CERN



Exploring Nanospace

Not all antimatter (positrons) are able to form Positronium; conditions do apply!

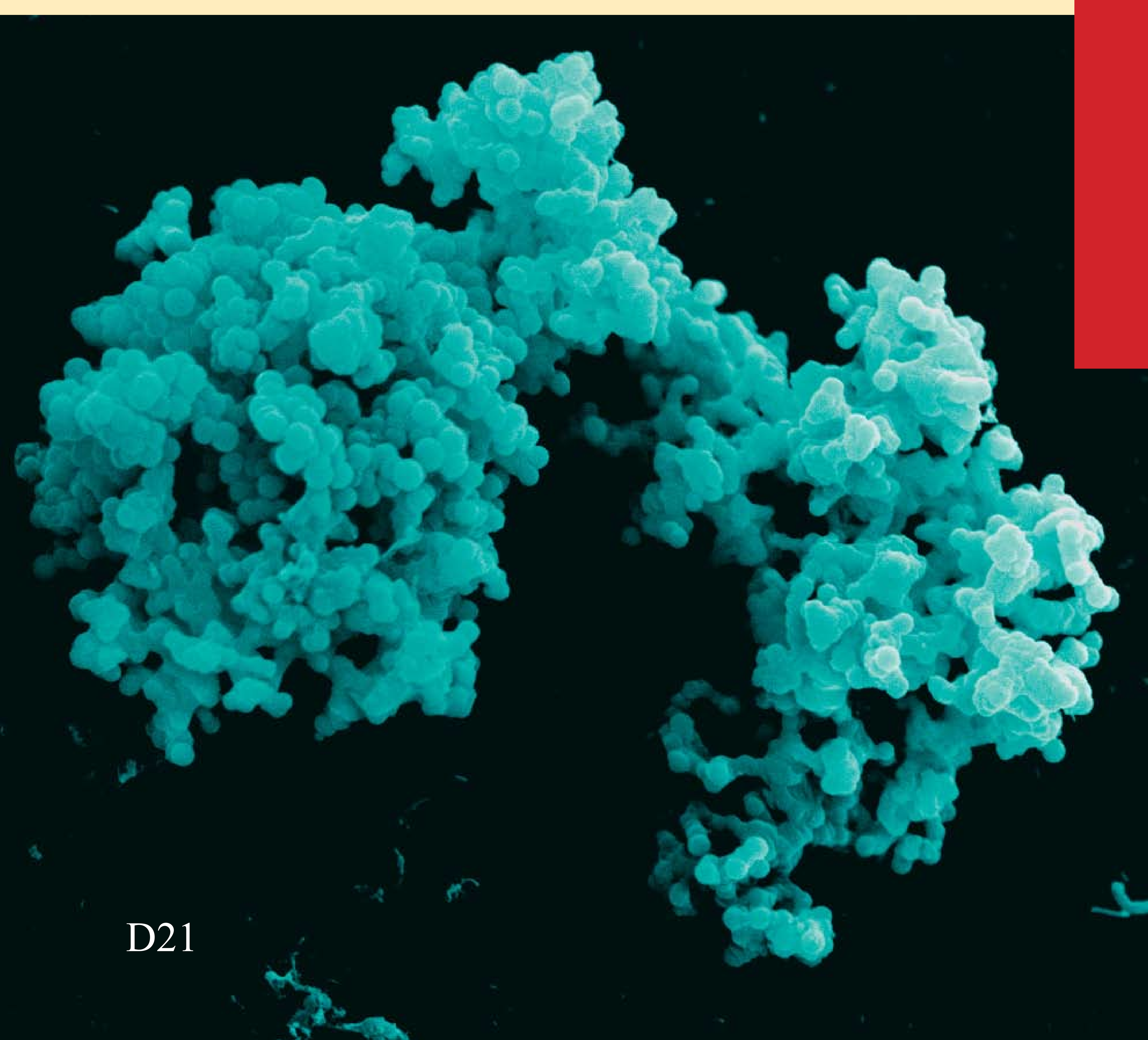
For Positronium to be formed we need our high energy positrons to *lose energy* through *interactions* with other particles. Once enough energy is lost the positrons are able to *entwine* with an electron *to form Positronium*. Throughout this process the positrons naturally migrate towards areas of low electron population (low electron density). It is these *open spaces* that allow the positrons to *survive longer* by forming Positronium.

The formation of Positronium *prolongs the lifetime* of the positrons before they annihilate; it is this lifetime that tells us so much about its *surrounding environment*.

This behaviour makes antimatter positrons *excellent probes* of nanospace, and porous material structures.

The information gained from this process tells us about the material's *properties*, such as their *porosity* and *conductivity*, and it can even show areas of *degradation in materials* long before they are visible to the human eye.

Image (below) courtesy of ANSTO



Anti-electrons (positrons) can be used to probe the open spaces in materials such as these tiny micro-particles which are used to store and release chemicals.

Nanomaterials

Why it is good to investigate nanomaterials using antimatter?

Antimatter (Positronium) probes are used to better understand the *structure* of nanospaces within materials in order to *improve* their engineering and functionality.

Positrons and electrons are extremely small and under the right conditions they unite to form Positronium. Positronium is small enough to *infiltrate the inner structure* of nanomaterials.

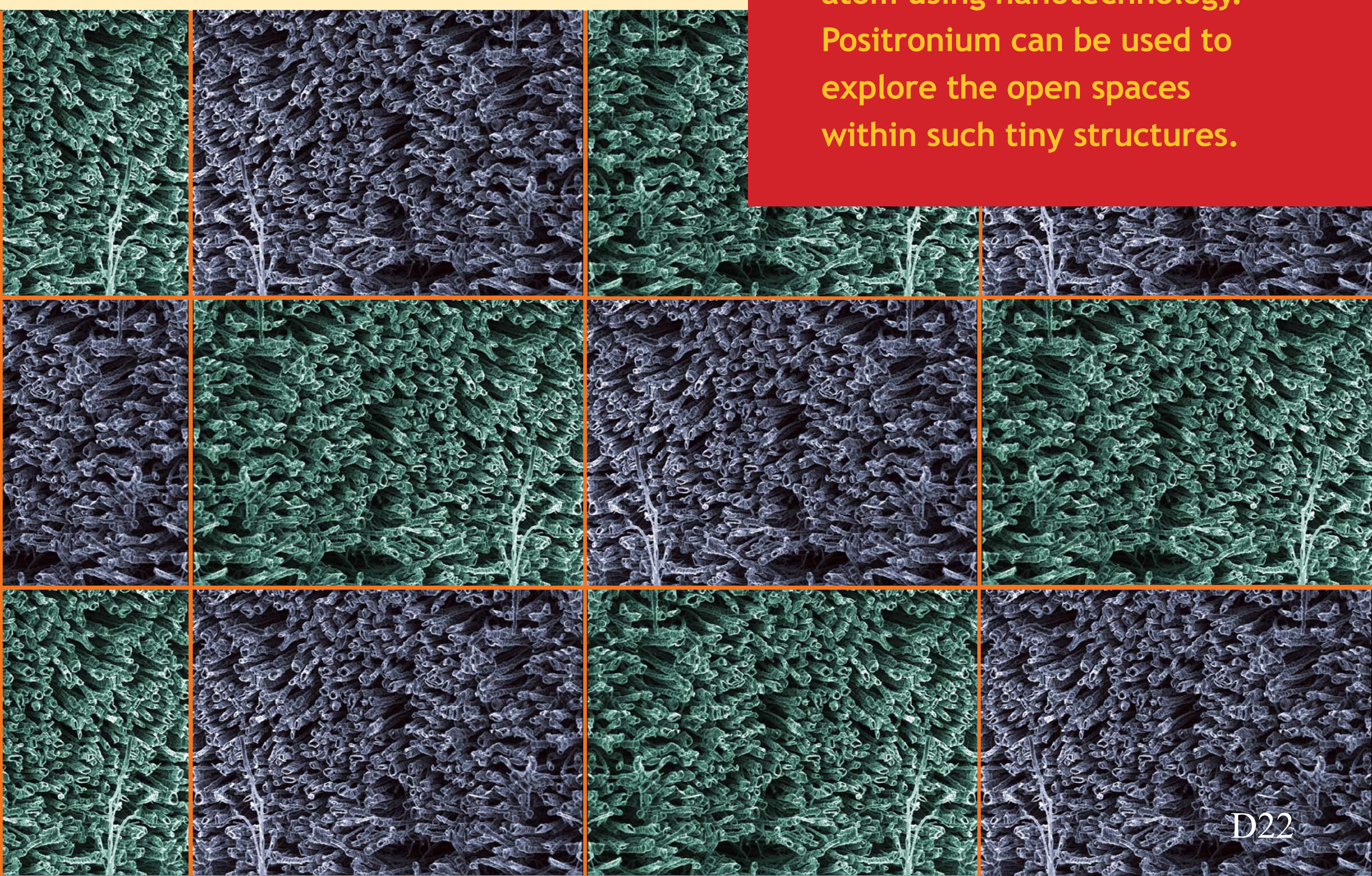
What are nanomaterials?

You may have heard of nanotechnology in science fiction or in the news. Nanotechnology refers to technological developments at the 10^{-9} (0.000000001 m) scale, a billionth of a metre.

Nanomaterials are materials that are modified on the *atomic level*, atom by atom, to create a larger, functional structure.

Materials that are best investigated with Positronium include *soft* (low electron density) materials such as, *plastics* and *membranes* for packaging, porous materials used in waste storage, controlled release *materials* for use in the medical and agricultural industries, *filters* and silica compounds.

Image courtesy of the Australian National University



These nanotubes are a billionth of a metre in size and were built atom by atom using nanotechnology. Positronium can be used to explore the open spaces within such tiny structures.

How can we use Nanomaterials?

Controlled release materials

Controlled release materials are used widely throughout *medicine*, *industry* and *agriculture*. One common use is in drug administration.

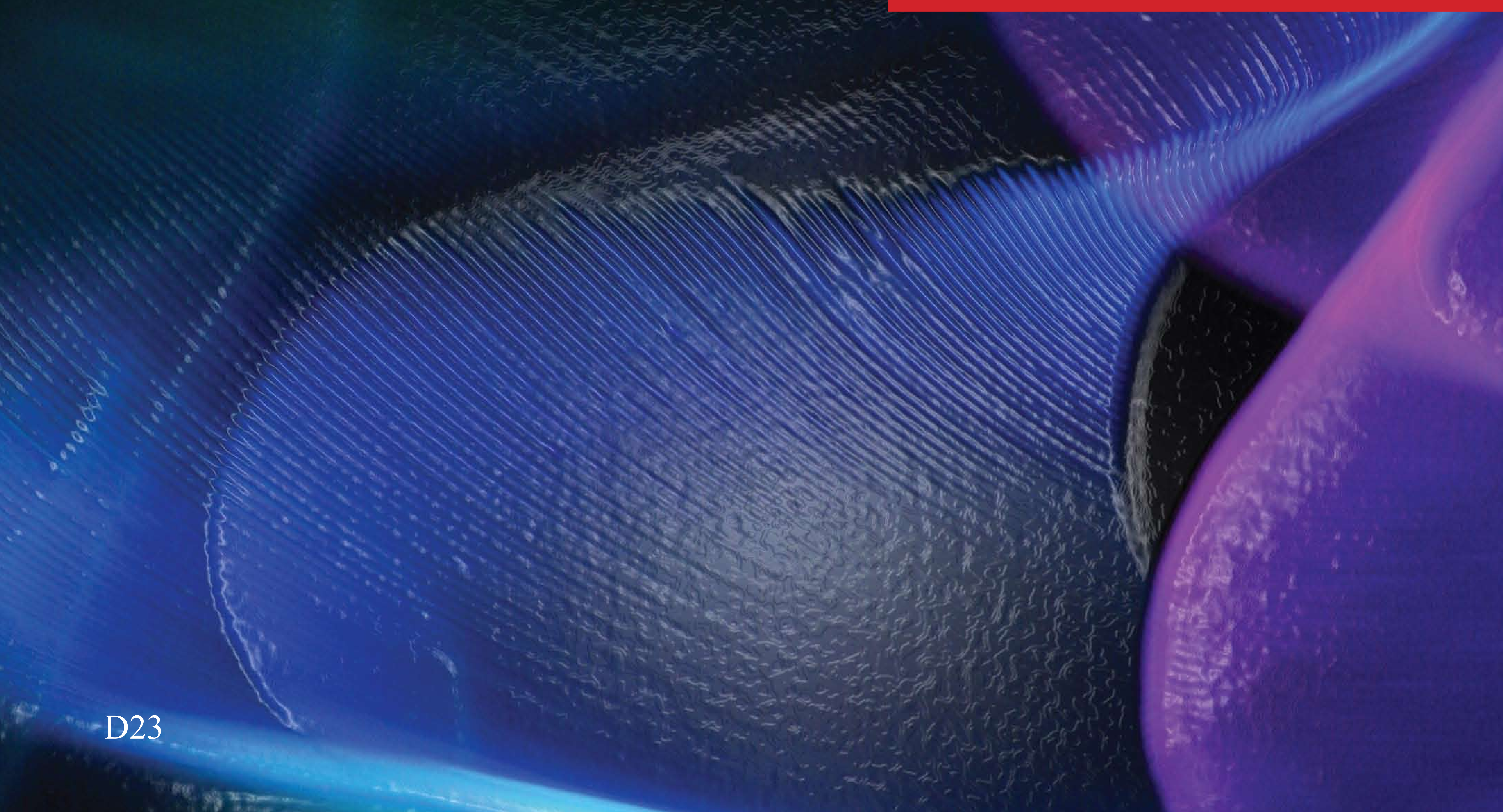
Slow release materials can be used for *controlled drug delivery* into the body. They work by reducing the flow of the chemicals into the system so that a *slow, steady state* of drug delivery is maintained.

The advantages of slow release drugs are that they can be taken less frequently than their instant counterparts, and they keep steadier levels of drug in the bloodstream.

Improving the functionality of slow release materials in drug packaging would allow the level of drugs administered to be sustained over a long period of time.

Image courtesy of jahdakine - aprés MAX

Nanosized materials such as these are used widely throughout medicine, industry and agriculture. Positronium exploration of nanospace can be used to improve the functionality of common household items—like the plastic food wrap that you use to pack your lunch!



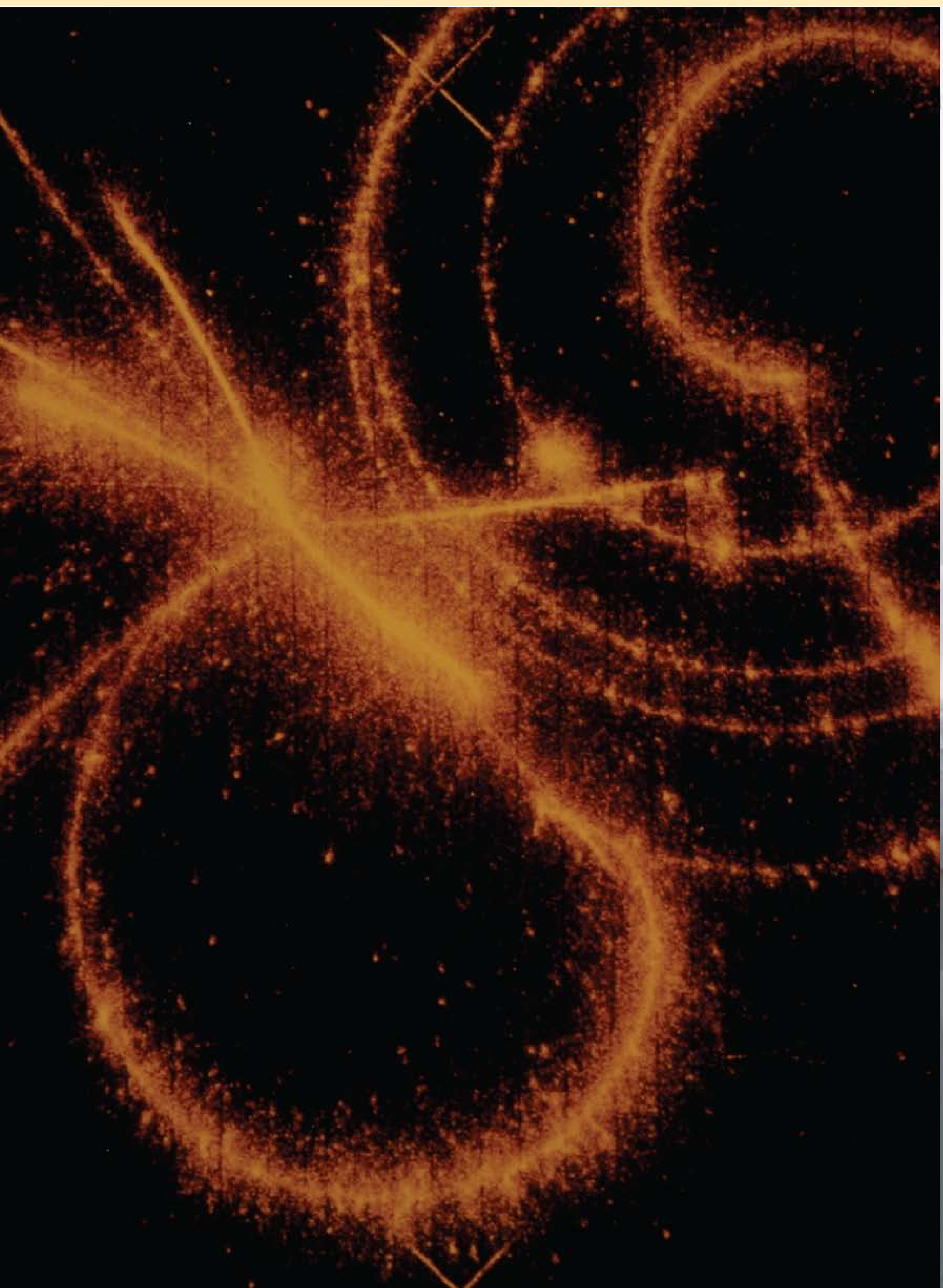
Antimatter and you

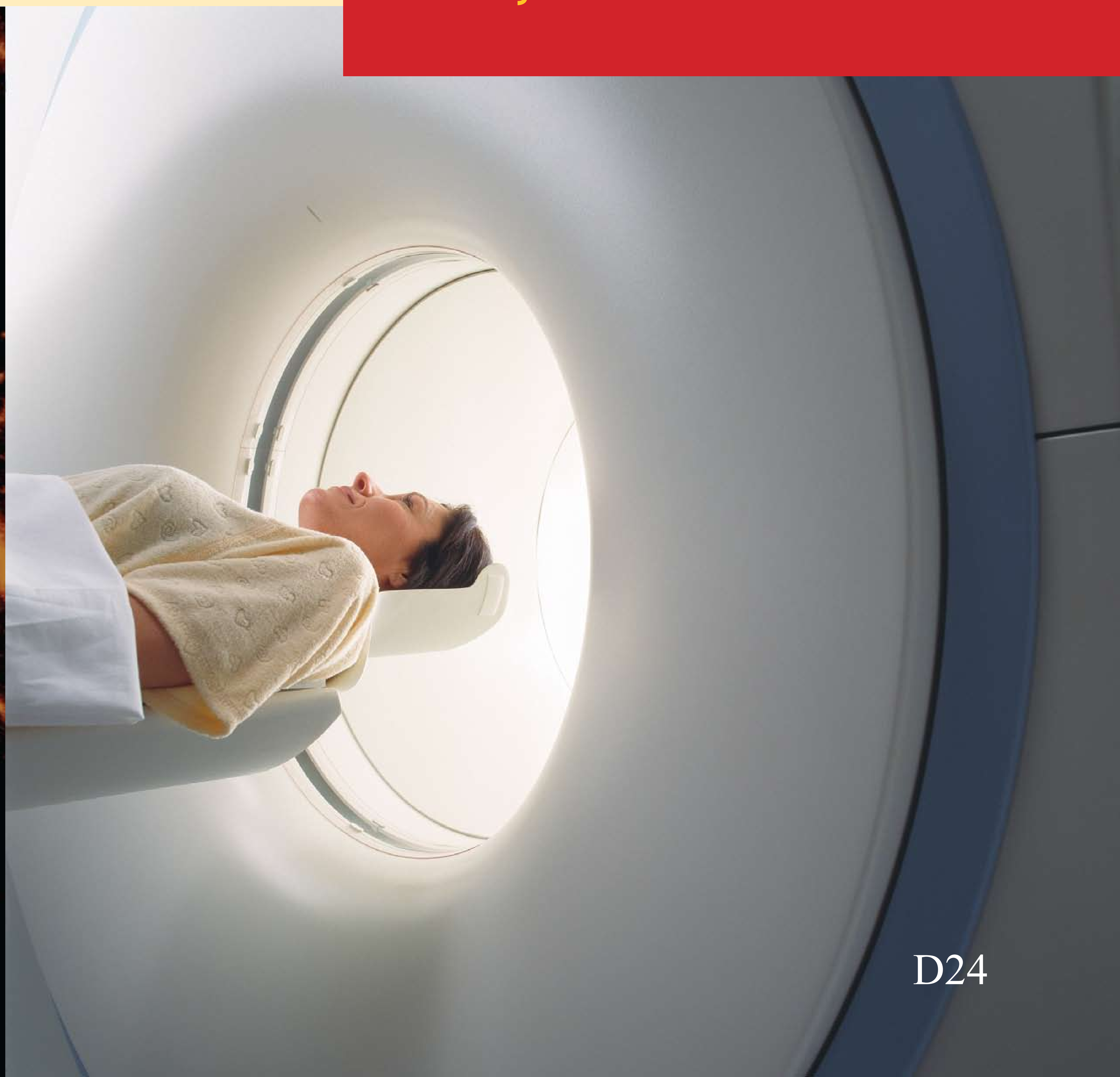
Antimatter is studied in *science laboratories*, used in *materials engineering* and plays a star role in *science fiction*. But one of its most important and well known roles is its use in *medicine*.

Antimatter, in particular Positronium, is used in *Positron Emission Tomography (PET)* scans which use the interactions between antimatter and matter to investigate bodily functions. PET scans are used *every day* in major hospitals all around *Australia*.

Image (above and below) courtesy of CERN;
Image (below right) courtesy of Siemens

Antimatter is used in medicine every day in Positron Emission Tomography (PET) scanners like the one seen here. PET scans use antimatter-matter interactions to investigate bodily functions.





Looking Inside

Antimatter is used in Positron Emission Tomography (PET) scans

You may know somebody who has had a PET scan.

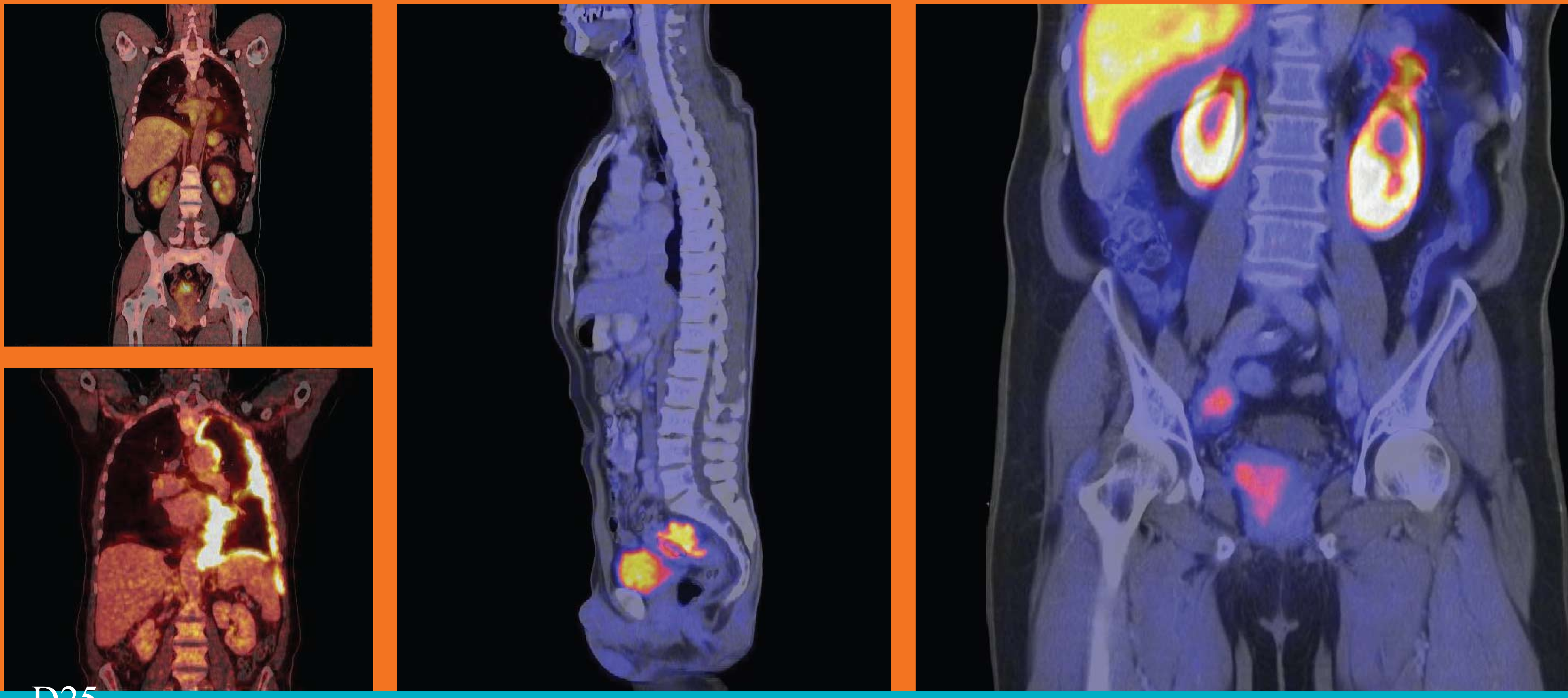
PET scans produce 3D, *computer constructed images* that measure and determine the function or physiology of a specific *organ*, *tumour* or other area of *high metabolic activity*. PET scanners can be used to detect and measure the severity of *cancers*, *cardiovascular disease* and to investigate *brain function*. PET scans can highlight areas of increased, diminished or no metabolic activity. They are especially good at investigating cancerous tissue, neurological disease, heart and blood flow problems and damaged body tissue.

Images courtesy of Siemens

PET scans are useful because they are relatively *non-invasive* and have a *resolution of a few millimetres*. This detail cannot be matched by any other common non-invasive techniques of cancer detection.

It is the behaviour of the antimatter positrons and the *lifespan* of Positronium that are amongst the *key* elements in the science involved in PET scanners.

These images are from a PET scan. PET or Positron Emission Tomography uses antimatter and matter interactions to investigate areas of high metabolic activity, such as abnormal growths, tumours and cancers.



Peering into a PET scan

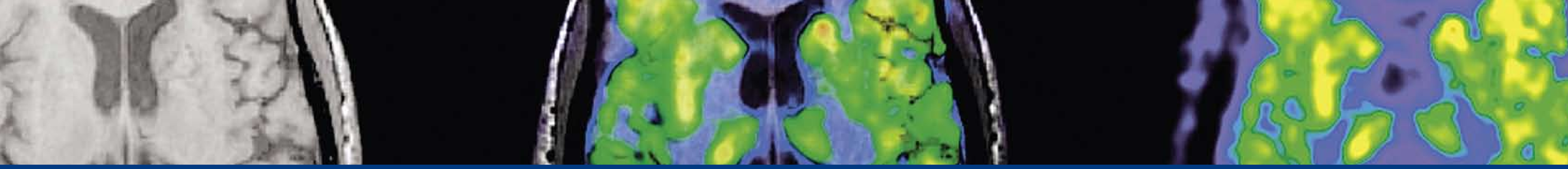
What could you expect when you have a Positron Emission Tomography (PET) scan?

- First the radiopharmacist starts by making a *radiopharmaceutical*—this is usually a *glucose* molecule that has a section replaced by a radioactive fluorine-18 atom—producing a molecule known as fluorodeoxyglucose (FDG).
- This commonly used *radiopharmaceutical*, containing glucose as energy for your body and radioactive fluorine that releases the antimatter *positrons*, is *injected* into your body.
- The glucose travels to areas where energy is needed in your body. These are the *areas of high metabolic activity*. Metabolic activity is the process where enzymes convert the chemicals in your body into energy.
- The fluorine is constantly *releasing high energy positrons*. The positrons cannot form *Positronium* with an electron until they *lose enough energy* through the interactions with molecules in your body.
- Once the positron has lost enough energy and found an electron to form *Positronium*, all in an area of high metabolic activity, it quickly *annihilates* giving off a *burst of energy* in the form of two gamma rays in opposite directions.

Don't worry, this is a completely painless process!

Image courtesy of Siemens

This image shows a patient going into a PET scanner. Before a PET scan a patient is injected with a radioactive marker or tracer that carries the antimatter around the body—don't worry, it's a safe procedure!



Making Pictures with PET

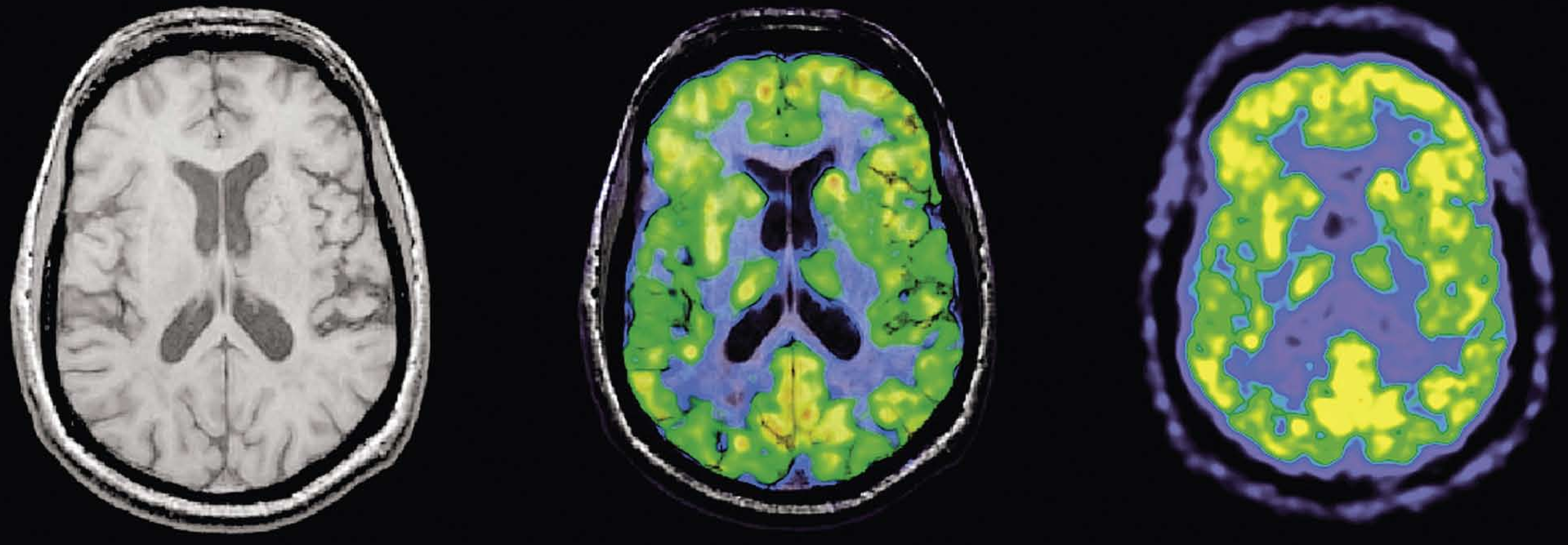
- The *Positron Emission Tomography (PET) scanner detects* the gamma rays, caused by antimatter-matter annihilation, and sophisticated software then calculates their *point of origin*.
- A computer assembles the detected signals to generate a *3D image* of your body highlighting areas of high metabolic activity. PET scans can *detect* cancerous growths and *abnormalities* of only a *few millimetres* in size. The technician can also track and investigate areas of high metabolic activity such as the heart, brain and the muscles detecting any abnormalities in their function.
- Radioactive fluorine, having a *half life of only 110 minutes*, lasts just long enough for the PET scan before quickly disappearing from your body.

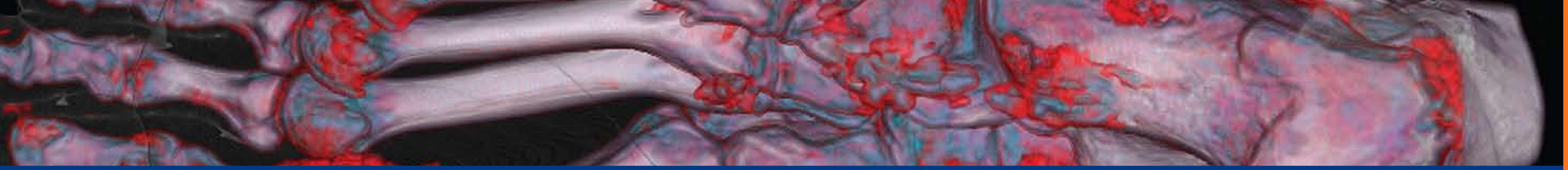
What is a half life?

Half-life is the measure of time taken for a radiopharmaceutical material to *decay* to half of its *initial strength*. In terms of radiopharmaceuticals the half life is the time taken for the radiopharmaceutical to decay to half of its original strength.

A radioactive tracer contains sugars that are drawn to areas of high metabolic activity. Eventually the antimatter annihilates giving off a small burst of energy. The PET scanner detects this energy and traces it back to its source, highlighting any abnormalities in the body.

Image courtesy of Siemens





What does PET show?

Positron emission tomography (PET) scans are particularly good for the early detection of small *tumours* in the lungs, head, neck, thyroid, brain and breasts. They are also good at detecting lymphoma, melanoma, colorectal, oesophageal, cervical and pancreatic cancers.

PET scans can also help to determine whether tumours are *benign* or *malignant* avoiding the need for unnecessary invasive surgical procedures.

PET scans vividly highlight areas where *brain activity* differs from the norm. They are useful in diagnosing dementia, Alzheimer's disease, Parkinson's disease, Huntington's disease, epilepsy, drug induced damage and other neurological conditions.

PET scans can pinpoint areas of decreased *blood flow*, identify blockages, and differentiate damaged from undamaged muscle. This information is important for people who have had heart attacks and are being considered for a procedure such as angioplasty, and in differentiating *malignant* from *non-malignant masses* such as scar tissue formed from radiation therapy.

Image courtesy of Siemens

This image is a PET scan overlaid on an image of the bones. It shows a person who has been seriously affected by gout. Notice how the PET scan can produce extremely detailed images of our insides.

PET in Australia

Positron Emission Tomography (PET) scanners are used *every day* for a variety of diagnostic reasons. There are presently *ten PET* facilities located in major hospitals around Australia.

Many PET scanners are located close to a *cyclotron*, a particle accelerator, used to make the radiopharmaceuticals for PET and other types of medical imaging.

Commonly cyclotrons are located close to PET facilities; this reduces the time needed for the transportation of the radiopharmaceutical to the patient. A short transportation time means that the radiopharmaceutical only needs to be made strong enough to last the length of the journey and the duration of the scan. Short transportation time also enables the creation of short-lived radiopharmaceuticals with differing and targeted functionality.

There are currently *eight cyclotrons* in Australia, in Sydney, Brisbane, Melbourne and Perth. These eight cyclotrons provide radiopharmaceuticals for the ten PET facilities in Australia.

At the ARC Centre of Excellence for Antimatter-Matter Studies (CAMS) some of our current research focuses on *understanding* the fundamental interactions that occur between positrons and body tissue, and ideas for *improving* existing PET techniques. Improvements include the use of lower energy particles and *different* radiopharmaceutical tracers to target different functionalities in the body and to improve *accuracy*.

Image courtesy of Siemens

PET scans are used in many major hospitals to detect cancers, growths, muscle and brain damage, and to monitor blood flow. PET scanners ideally need to be located close to a cyclotron (particle accelerator) where the antimatter and the radiopharmaceutical tracers are made.

Antimatter for the Future

Current antimatter research at the Australian Research Council Centre of Excellence for Antimatter-Matter Studies (CAMS)

At the ARC Centre of Excellence for Antimatter-Matter Studies (CAMS) we research the ways that antimatter, in particular positrons, interact with matter including atoms, molecules, materials and bio-molecules.

Research at CAMS is focused under three broad research themes:

1. Fundamental studies of antimatter-matter interactions and their applications

We conduct research to provide unique 'benchmark' data—reference standards for both experiment and theory—which can be used to test our knowledge of the fundamental interactions of positrons and electrons with matter, and which will ultimately underpin future applications of positron and electron-driven processes.

2. Positrons and electrons as probes of materials and surfaces

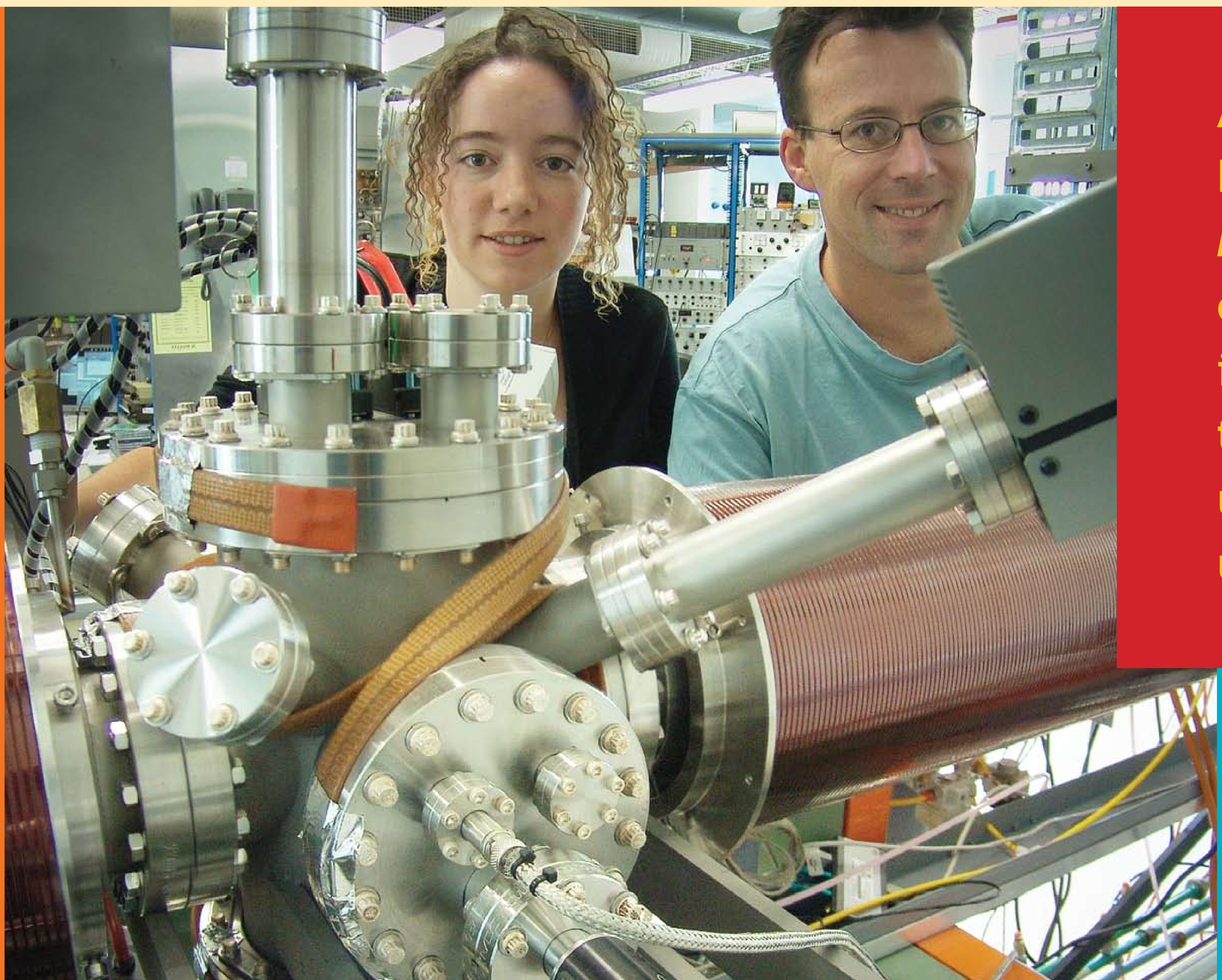
We use a variety of techniques to probe surfaces and bulk materials. These techniques use positrons, electrons and various other nuclear probes.

3. Positrons and electrons in medicine and biology

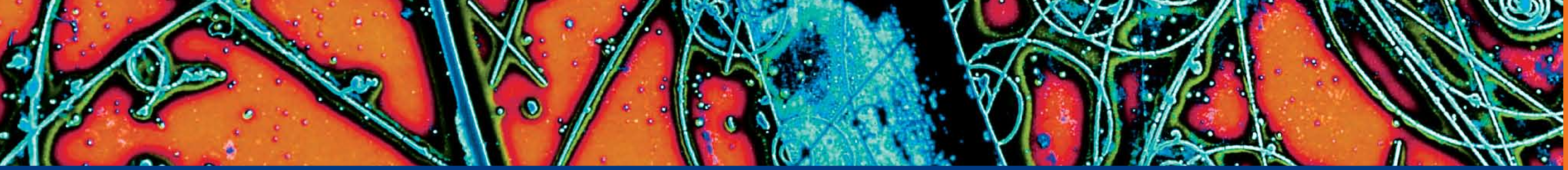
We focus on increasing the usability of both low energy electrons and positrons in medical applications such as Positron Emission Tomography (PET) and positherapy (positron therapy).

CAMS' research facilities are spread across Australia with nodes in Canberra (Australian National University), Sydney (Australian Nuclear Science and Technology Organisation), Adelaide (The University of Adelaide and Flinders University), Townsville (James Cook University), Darwin (Charles Darwin University) and Perth (Curtin University and University of Western Australia). We have international partners in the USA, San Diego, Davis, Iowa, Nebraska (San Diego State University, University of California, Drake University, University of Nebraska and Lawrence Berkeley National Laboratory), Japan (Tohoku University, Sophia University and Tsukuba University), and Italy (University of Trento).

Image courtesy of the Australian National University



At the ARC Centre of Excellence for Antimatter-Matter Studies (CAMS) part of our research focuses on improving PET scan technology through a better understanding of the underlying processes.



Want to know more?

Visit www.positron.edu.au

ARC Centre of Excellence for
Antimatter-Matter
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