CHEMISTRY FOR A BETTER LIFE

The decadal plan for Australian chemistry 2016–25

Part 2: Appendices 12 to 15

A report prepared by the Decadal Plan Working Group
on behalf of the National Committee for Chemistry

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Executive summary

The members of the Chemistry Decadal Plan Working Group initiated 26 town hall meetings across Australia as forums for all segments of the chemistry value chain to voice and discuss their concerns about chemistry in today's national and global working environment. Overall, approximately 700 people from industry, the school and higher education sector and the research sector, as well as service providers to these sectors, contributed to the town hall meetings.

Research funding issues were deliberately left out of the discussion to avoid participants focusing mostly on the funding required to solve problems.

A number of important issues were identified that added depth and breadth to the findings of the individual interviews and surveys undertaken as part of the decadal plan process:

1. The negative image of chemistry was seen as a major contributor to the perceived unattractiveness of any career that contained the words 'chemistry', 'chemical' or 'chemist'.
2. The general public has poor levels of chemistry literacy. This includes parents who want their children to pursue a rewarding career with a future.
3. Teachers are not sufficiently able to engage students in chemistry at all levels.
4. Primary and lower high school science teachers have poor chemistry literacy. This results in low uptake of the subject of chemistry by students, poor chemistry teaching outcomes and uninformed career choices.
5. Chemistry is not universally seen as a satisfying career. As the breadth of career options has not been made clear to students during their school years, they have to play catch-up to gain sufficient skills once they enter a university course commensurate with their entry scores.
6. The decline of the chemical industry in Australia is contributing to the perception that studying chemistry is unlikely to lead to a rewarding career in the future.Many people working in chemistry jobs in industry have no degree in chemistry. There is a perception that industry does not value chemistry graduates as they are believed to be more expensive than people trained to just do chemistry jobs.
7. There are structural issues with the provision of chemistry higher education across the country, as well as with the quality of chemistry course entrants in smaller and regional universities due to the 'flight' of high achieving high-school leavers to capital cities. This results in a second and third tier chemistry education in Australia.
8. The job readiness of graduates could be improved by providing more practical interaction with industry during undergraduate and postgraduate courses.
9. There were few specific ideas about what new research questions should be addressed by the research sector. This could be attributed to the town hall meeting format, in which new ideas were not shared.
10. The need to maintain the current large research infrastructure and, more importantly, to consistently upgrade to a world-class level, was identified as a major requirement by the research sector. This consistent upgrading is needed to maintain world-class research and national competitiveness in research capability.
11. The interaction between industry and the higher education and research sector was one of the major issues that the decadal plan is expected to address. The relationship, that both

industry and the higher education and research sector desires, does not function well. However, there are currently no constructive ideas that can be implemented quickly for economic benefit. The inflexibility of the current higher education and research and development sectors, and especially their administration arms, in dealing with industry was seen as a major barrier to a constructive relationship.

12. The town hall meeting participants were overall quite pessimistic about the ability of the chemistry value chain to implement any of the recommendations of the decadal plan. This is due to the fact that there is, under the current organisational structures of RACI, PACIA and the National Committee for Chemistry, no single body that can speak for all sectors of the value chain.

The town hall meeting process proved efficient and allowed many people to contribute to the content and development of the Chemistry Decadal Plan.

Introduction

The terms of reference for the National Committee for Chemistry, as set down in 2013, included the development of the Chemistry Decadal Plan for the years 2016 to 2025.

The Decadal Plan Working Group agreed on a complex process of stakeholder consultation and requirements validation to ensure the eventual recommendations of the decadal plan would align with the chemistry value chain requirements.

The overall decadal plan process is summarised in Figure 1.

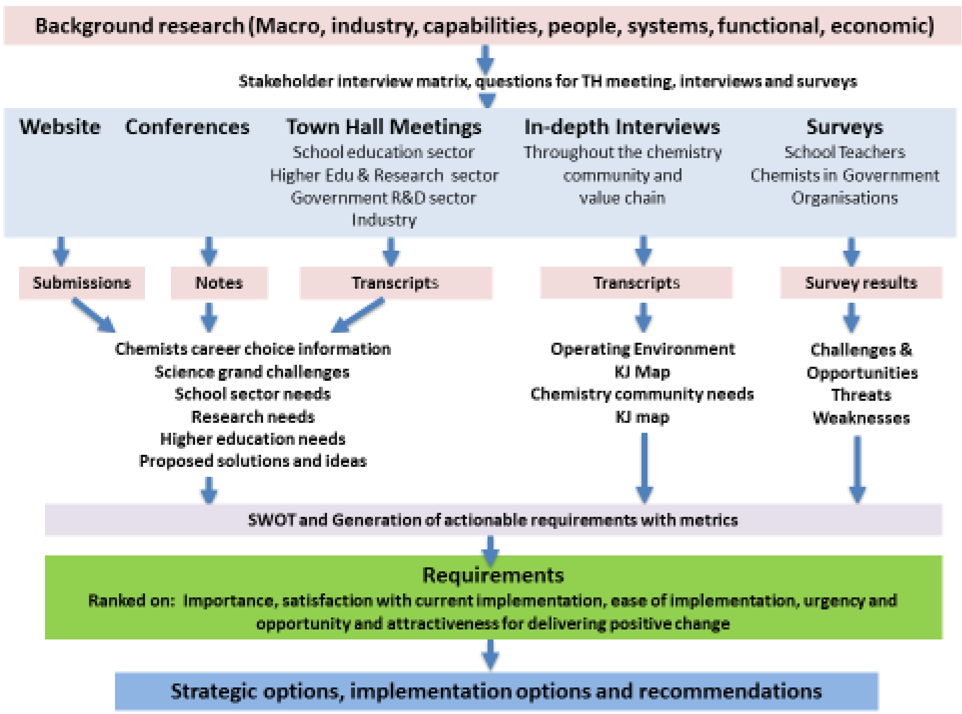

Figure 1: Decadal plan process

This report summarises the issues and requirements voiced during the 26 town hall meetings held from July to December 2014 at research organisations, science teacher association meetings and the RACI conference. In addition, two industry stakeholder meetings were held in Melbourne and Brisbane.

Meeting dates and locations are shown in Table 1.

Attendance at the meetings varied, with most attracting between 15 and 40 participants. The largest meeting was the BioMelbourne Network industry breakfast, with approximately 100 participants, including people from industry and the research sector, as well as intermediate service providers such as consultants and IP professionals.

The total number of participants at all town hall meetings can only be estimated as no log of participant numbers and names was kept. Overall, approximately 700 people contributed to the meetings.

	Town hall meeting	Date (2014)	Location
1.	CONASTA high school conference	9 July	Adelaide
2.	University of Melbourne	29 July	Melbourne, CIC
3.	Flinders University	19 August	Adelaide
4.	University of Technology, Sydney	20 August	Sydney
5.	Monash University	20 August	Melbourne
6.	University of Sydney	27 August	Sydney
7.	Opal Auditorium, ANSTO	28 August	Lucas Heights, NSW
8.	University of New South Wales	28 August	Sydney
9.	Women in Chemistry	2 September 2014	Melbourne
10.	South Australia RACI branch meeting	15 September	Adelaide
11.	University of Queensland	15 September	St Lucia, Qld
12.	SETAC Asia–Pacific conference 2014	16 September	Adelaide
13.	Charles Darwin University	22 September	Darwin
14.	CSIRO Clayton	9 October	Melbourne
15.	Charles Sturt University	10 October	Wagga Wagga, NSW
16.	Industry forum on the future of the chemical industry in Australia	14 October	Brisbane
17.	Curtin University	22 October	Perth
18.	University of Western Australia	31 October	Perth
19.	Queensland University of Technology	6 November	Brisbane
20.	Griffith University	13 November	Griffith,
21.	BioMelbourne Network breakfast: 'Future of chemistry, future of manufacturing'	25 November	Melbourne
22.	University of Wollongong	25 November	Wollongong, NSW
23.	QUT–STAQ annual workshop: 'A forum for Qld chemistry & science teachers'	28 November	Brisbane
24.	Australian National University	4 December	Canberra
25.	RACI national conference	8 December	Adelaide
26.	James Cook University, Townsville and Cairns (via web link)	9 December	Townsville and Cairns, Qld

Table 1: Town hall meeting dates and locations (2014)

Town hall meeting process

The town hall meetings were widely advertised within the relevant research organisation and their local departments/divisions/campuses and by the relevant conference organisers.

In general, the town hall meetings were organised and promoted by the relevant head of the organisation, the head of the chemistry department, the Dean of Science, a member of the National Committee for Chemistry, or a member of the Chemistry Decadal Plan Working Group.

The industry meeting in Melbourne was organised and promoted by the BioMelbourne Network.

Each of the town hall meetings was introduced by the meeting organiser or a Decadal Plan Committee member. A short PowerPoint presentation gave an outline of the decadal plan process, followed by a set of five to eight slides with questions to guide the discussion.

Four to five of the following questions, or an evolving version based on the outcomes of previous meetings, were presented for discussion by town hall meeting participants:

- At what age did you first get interested in and who or what influenced you to embark on chemistry?
- What is the definition of chemistry today so we can provide the right education?
- Is chemistry a discipline or a career choice?
- Does chemistry have an image problem and how can we overcome it?
- What challenges will chemistry higher education face during the next decade and what will the impact be over the following decades?
- What challenges will chemistry education face in the school education sector and how can we overcome these?
- How relevant is chemistry today and what are the research questions that will keep it relevant in the future?
- How essential is large research infrastructure for chemistry research and what role will they need to play in the future?
- Industry—how can we understand the diversity of opportunities that will arise in the future and how can we prepare our students for them?
- How do we work with industry? What works and what does not? What needs to change?
- Who should be responsible for implementation of the decadal plan recommendations?
- If there was a magic wand to change for the better how chemistry works and performs in Australia, what would need to be changed?

To entice leaders and R&D staff of industry companies to attend the industry-focused town hall meetings, a more targeted approach was taken through telephone and email invitations to individuals and via industry networks. At the two industry-oriented town hall meetings, industry personnel presented their view via PowerPoint presentations. This was followed by discussions with other industry leaders and researchers and Decadal Plan Committee members.

Analysis of town hall meetings

Each of the meetings was recorded, using either the organisation’s recording technology or digital pocket recorders.

The recordings were analysed to identify common issues throughout the chemistry value chain, as well as those specific to individual stakeholder segments. The focus of the analysis was the identification of **new issues** that were **not** identified using the other research methods, such as stakeholder interviews and surveys.

The following gives a summary of the analyses of the town hall meeting recordings.

Results

Question: At what age did you first get interested in and who or what influenced you to embark on chemistry?

There were three types of answers:

1. The first group got excited about chemistry in primary school without having an idea about what 'chemistry' was. They were usually introduced to it accidentally either by a parent or teacher and stayed excited ever since.
2. The second group became interested during their high school years, either because they had to do chemistry and eventually liked it, or because a teacher had a specific interest in chemistry and could make it exciting.
3. The third group made up their mind in university or later in life, or stumbled into it.

For most respondents, a teacher's or lecturer's enthusiasm for chemistry was the most important influence, and instrumental in their decision to take up chemistry seriously at high school and university—even though it was often perceived as a difficult subject.

Question: What is the definition of chemistry today so we can provide the right education?

In earlier decades there was a clear understanding of what chemistry was, and what it represented to the general public and school students.

Today, there is a confusion about what 'chemistry' is. There are 'chemists' running pharmacies, and 'chemists' who work in chemical manufacturing companies as analytical or formulation chemists, or in pharmaceutical companies in new product development.

There is also a widening of the breadth of chemistry sub-disciplines or, as one participant described it, a splitting up of chemistry into several tribes, and increased tribalism within the chemistry community. Examples given were biochemistry, physical chemistry, protein chemistry, forensic science, geochemistry, and a number of other 'chemistries'.

This tribalism was seen as the result of the perceived poor image of chemistry in the public eye, and as an attempt to attract students into the chemistry-based science field by giving it a more attractive name and positive image.

Overall, tribalism was seen as counterproductive in the long run, and not conducive to developing a cohesive teaching curriculum for both the school and higher education sectors and the various sister disciplines that rely on their graduates having had a solid chemistry education.

Question: Is chemistry a discipline or a career choice?

The discussion around this question developed throughout the town hall process. The concept of chemistry as a discipline appears to have evolved over the last decades, with various 'sub-disciplines' appearing on the scene.

In addition, the increased interdisciplinary reliance on chemistry (physics, pharmacology, geoscience, space science, agriculture, medicine, and so on) makes it difficult to define the boundaries of chemistry as a discipline. For school and university students, parents and the general public to be able to understand the value of chemistry, it must be 'describable'. Understanding what chemistry is will enable them to make positive career choices that include the various shades and persuasions of chemistry.

Overall, there was consensus about the positive value of chemistry to society. However, the decline of the chemical industry in Australia over the last three decades was seen as an indication that chemistry is not valued in this country, making it difficult to promote to incoming students.

In countries with a strong chemical industry (such as Switzerland and Germany), chemistry is viewed as an excellent career path. Other countries with advanced manufacturing industries (such as Singapore) also value chemistry.

The strong connection of chemistry career choice and job availability in Australia was seen as a big issue that presented an almost insolvable conundrum: how can we promote chemistry as a career choice if the industry that has traditionally taken on graduates is disappearing? How can we make chemistry an attractive choice for university graduates if we do not have alternatives to our current chemical industry?

Even though knowledge of chemistry is required in many other careers that do not contain the term 'chemistry', many school teachers do not have sufficient knowledge of chemistry to be able to provide school students with an understanding of how chemistry fits into today's world and careers.

Town hall participants voiced the opinion that there is a need to conquer the vocational uncertainty surrounding chemistry—an uncertainty that is not seen in relation to other degrees like pharmacy, medicine or law. Generally, mostly chemists and teachers cannot answer questions from students and parents such as: what is a chemistry degree for? Is chemistry specific or does it give transferable skills? Are scientists trained in a subject area in order to do a specific job i.e. a chemist does the job of a chemist? What do chemists do?

Question: Does chemistry have an image problem and how can we overcome it?

There was strong agreement across all of the town hall meetings that Chemistry has a significant image problem. Large media outlets focus on the 'bad news' of chemistry, and the 'good news' of space science. One participant put it this way: 'In the eyes of the public, the medical profession and the pharmaceutical industry save lives and chemists cause toxic spills, chemical warfare and pollution'.

Chemicals are generally seen as 'bad'; people prefer to buy 'natural' medicines and products rather than synthetic 'chemicals'.

Chemistry's public image was seen to stem from insufficient chemistry education and poor understanding in the community, which breeds fear and suspicion (of nanomaterials, for instance).

To some extent, chemistry's poor image was seen to be a result of its successes—in developing pesticides and herbicides, for example.

One factor seen to be contributing to the negative image of chemistry was the fact that many people employed in chemistry-based jobs call themselves ‘chemists’, even though they don’t have a chemistry qualification. This was seen as damaging to the image and professionalism of chemistry.

Chemistry’s poor image among the general public appeared to be more disturbing to the higher education sector than to industry and the government research sector.

The perceived lack of chemistry-related jobs in regional and country areas, combined with chemistry’s poor image, was seen as an obstacle to attracting bright students from these areas into chemistry careers.

There were not many ideas, however, about how to overcome this poor image in the long run, except by trying to demystify chemistry—either by using specialist media and communications or showing the public how chemistry contributed to their current good lifestyle.

The United States has had very popular science communicators, such as Carl Sagan for astronomy. However, in Australia there are few role models in the areas of chemistry or science. Most children would like to grow up to be a fireman or astronaut, rather than a chemist. Better role models are needed.

There is no common chemistry outreach program that is agreed on and consistently implemented by all sectors of the chemistry value chain.

Question: What challenges will chemistry higher education face during the next decade and what will the impact be over the following decades?

One of the strengths of a chemistry degree is the breadth of knowledge it provides, enabling people to move easily into areas related to chemistry, such as engineering, mining, biology, environmental science and agriculture.

The view was expressed by several people at different meetings that: in the past, it was possible to do a course which focused on analytical chemistry, for example. Conversely, current students have a very large choice of subjects and they end up doing a wide range of subjects but not in depth and they end up with a qualification, that does not give them sufficient focus to be a good chemist. Consequently, they are not attractive to employers.

Most of the people currently employed as chemists do not have chemistry qualifications. Participants expressed the view that no other profession would tolerate this situation (doctors and lawyers who were not qualified, electricians who did not have their three-point plug changing licence, and so on). Almost every profession controls who can practice it. Chemistry does not, but it needs to develop a plan to ensure that the professional image of those with a chemistry degree is upheld.

The Go8 universities attract numerous bright students who have achieved the necessary skills and knowledge required to study chemistry. Nevertheless, increasingly, at all Universities, but especially, in the smaller and regional universities, more and more students are enrolling in science or chemistry courses, who have not taken any chemistry subjects at school.

Small regional universities, in particular, were suffering, as good high-school leavers fled to universities in the capital cities, while those with the lowest chemistry knowledge were enrolling in regional universities. In the past, some regional universities had high skills, and critical mass in specific chemistry-related research and industry support areas. However, in many cases this critical mass has been eroded, leaving regional universities to cater for large cohorts of poorly educated school leavers and distance education students who wish to pursue careers only in their local vicinities.

It is currently not clear how many chemistry graduates Australia needs, how many are exported overseas or how many Australia imports from abroad. This reflects poor communication between the industry and education sectors.

It was agreed that it is common to receive over 100 applications for a chemist position, with 50 per cent of the applicants having no chemistry qualifications whatsoever. Applicants appear to believe that qualifications are not necessary; universities need to change this perception. In the end, only a small percentage have the right skills and are employable.

There was a degree of disillusionment among the participants of town hall meetings in higher education institutions about the long-term availability of career paths in Australia for chemistry graduates, especially those who also had postgraduate degrees and experience. There is a perception that universities produce what industry demands, but that there is no demand for chemists in Australia.

Education fields such as pure chemistry, applied chemistry, biochemistry and other chemistry disciplines need to be driven by jobs in Australia to match job types and numbers of employed chemists with the number of places available in universities.

Participants believed that universities need to have more involvement with school curriculums, and that the secondary–tertiary interface would benefit from more frequent interactions and better mechanisms for communication.

There was a suggestion that there are too many chemistry programs/departments in Australia and that only half of them are needed. This would overcome the problem of some universities being left with students who have no entry level skills in chemistry; they could then focus on service delivery and applied research for locally based specialised industries that need chemistry research and analytical skills in their specific field.

One factor contributing to graduates having insufficient skills is that universities increasingly believe chemists can look up any information they need, rather than having to remember it. Some graduates indicated that they do not have the basic understanding of the subject which they need to resolve problems. They attempt to follow a recipe instead of trying to understand the problem. New mechanisms of knowledge transfer and retention are required so that new graduates are more able to solve and address problems, and are therefore more employable.

There was a perception that universities should therefore teach more problem-solving skills, as well as technology-based skills, as many graduate chemists appear to have little knowledge of the theory of operation of the instruments they use.

As chemists in today's work environment are required to have many skills including in business, good communication and writing, there should be a greater focus on those skills in undergraduate and postgraduate courses.

Cadetships, internships, sandwich courses and work experience were seen to provide some needed practical experience in the real world, enabling graduates to decide which field of chemistry they like and become more job ready. However, there is an issue with availability and equality of access.

One issue that was perceived to be common across all sciences was the 'disappearance' of women from chemistry research careers. Although there are fairly equal numbers of men and women graduating with chemistry degrees, there are fewer female career researchers in higher positons and management roles, in both higher education and research organisations. Participants were pessimistic about the possibility to change this situation, due to the current reward structures, which penalise employees who work part-time or take unpaid leave. The current structures penalise women who try to partition their lives between family and career.

Question: What challenges will chemistry education face in the school education sector and how can we overcome these?

Problems with chemistry education start at school; early chemistry content is dry and not made interesting.

There was a clear view that students suffer from increasingly shorter attention spans, and this in turn is making the teaching of chemistry more difficult; there was a perceived need to embrace new ways of teaching chemistry.

It was suggested that one way to address the public's generally poor chemistry literacy is to make chemistry compulsory in senior high school. This would give everyone a foundation in chemistry, regardless of what degree and profession they ultimately choose—akin to essential literacy and numeracy skills. This would help educate the general public to a level that might overcome negative and pseudoscientific beliefs that are contrary to chemical principles.

Regional and rural high-school leavers have poor or non-existent chemistry skills. The reason for this was seen as being the lack of science teachers with a chemistry background in rural and remote areas, and the belief that there were no locally available jobs which would justify a teaching focus on chemistry.

Many BEd students graduate from universities in regional centres and capital cities each year, going on to become science teachers—however, they quickly become isolated from their university. Universities should be expected to provide an ongoing open door policy to assist their alumni with their teaching in their area of specialisation.

There was an overall consensus that chemistry teaching skills at the primary and lower high school levels were poorer than they should be. Although science teachers were enthusiastic, the fact that ongoing professional development was not accessible to all was an issue.

In general, there was agreement that chemistry should be taught from a much earlier age, as the negative perception of chemistry is formed early. The fact that there are currently very few primary schools with a science teacher with a science degree or specialisation makes this very difficult.

It was suggested that young children could be taught about molecules, as primary school students are already familiar with Lego and various other building-block based games.

Question: How relevant is chemistry today and what are the research questions that will keep it relevant in the future?

There is very little chemical manufacture in Australia. Universities and government research laboratories need to collaborate with companies that manufacture chemicals, even at the SME and small-scale level, and to focus on the manufacture of niche products.

Most of the chemical industry companies in Australia are SMEs and many of these are not aware of the opportunities that good R&D can provide. Many of the research questions are not voiced and not known to both industry companies and research organisations.

Although chemistry and chemistry research were seen as highly relevant to solving many questions and problems at both the local and global level, Australia's chemical SMEs appear to focus mostly on the local market. It was felt that they did not have the highly developed capacity to address larger problems that would make them globally competitive.

There was agreement that universities need to assist the chemical manufacturing industry and help it expand. This would provide a win-win situation for both sectors.

There was general consensus that curiosity-driven research by individuals, universities and research labs was the best way of finding solutions to globally important problems.

It was suggested that a survey be conducted to determine what the Australian public sees as the most important problems that could be addressed by science. This would enable a more focused pursuit of research questions in which the general public is interested, and which it would therefore be more likely to fund.

In terms of the big research questions of the future, responses were along the same lines as those already identified via other research methods—alternative energy, clean water, recycling, new materials in a world of global warming, and addressing the major global threats facing the human race.

Question: How essential is large research infrastructure for chemistry research and what role will it need to play in the future?

The consensus was that chemistry needs research infrastructure at the small end of the scale; there are many labs, and they need to be equipped and staffed appropriately.

Chemistry does not need the equivalent of a Square Kilometre Array. However, access to existing large research infrastructure, such as the Synchrotron and the OPAL reactor, was thought to be of utmost importance. It was also agreed that this infrastructure needs to be upgraded consistently and in a timely fashion so that it can provide the necessary resources to conduct world-class research without becoming irrelevant or being superseded in a few years.

Providing the necessary technical support structures and staffing levels for these large infrastructure items, so that research throughput, efficiency and productivity can be improved, was thought to be of high importance.

Another issue of concern was the lack of a common national register of second-tier research infrastructure so that researchers could find out what equipment was available in their vicinity or in other locations.

Question: Industry—how can we understand the diversity of opportunities that will arise in the future and how can we prepare our students for them?

There are many opportunities in the field of chemistry, but graduates need the basic skills.

There was a perception that many graduates do not appear to retain the basic information communicated to them during their course once they have been working in industry or the education sector for a while.

Universities need to maintain basis chemistry as an important component of all fields of science, such as environmental science, biology, engineering, agriculture and manufacturing. This was seen as important as not all specialist developments that will lead to new industrial opportunities can be foreseen.

The issue identified was that there is a focus on the perceived needs of a side discipline first, then on the basics of chemistry that make this side discipline highly successful. For example, it was thought that one important and broad field, molecular biology, currently focuses on biology first, and on chemistry second—the result is that people working in the molecular biology field lack chemical knowledge. This is also seen in other fields such as agriculture, microbiology and geology.

Although internship programs for undergraduate students in industry or government labs were seen to be beneficial to both the student and the profession, there is an obvious issue of supply and demand. Currently, there is a lack of engagement between university and industry and it is likely that there would be shortages of placements if such programs were implemented.

It was suggested that the quality assurance aspects of analytical chemistry, toxicology and chemistry in the regulatory context all provided potentially important new or emerging chemistry fields.

Question: How do we work with industry? What works and what does not? What needs to change?

Facts about the Australian chemical industry (for example, the PACIA Roadmap) need to be highlighted to demonstrate the importance of chemistry to industry, employment and the economy. The chemical industry continues to support mining, agriculture, manufacturing, and so on.

Many of the larger chemical companies are in the process of relocating, or have already relocated, their commercial research laboratories closer to their global customer base because they experience problems competing with laboratories in Asia if they remain in Australia. It is claimed that high wages and materials costs in Australia result in a low level of innovation, few clever ideas and a lack of problem-solving capability at a local industry level.

The view was that universities were not collaborating at a consistent level with industry. There was a belief that interactions with industry were mostly based on meaningful personal relationships or individual–industry consultations, rather than on an overall, government-enabled plan.

There was also consensus that the role of CSIRO of providing research capability for industry in Australia, and especially for SMEs, was not understood by either industry or the university based research providers.

The consensus was that the needs of industry were more urgent and required immediate solutions, whereas the research sector was used to solving problems in a five-to-10year timeframe.

Town hall attendants perceived that, overall, the research sector lacked flexibility in dealing with industry companies; the focus on existing funding mechanisms did not make it easy to establish close and lasting industry relationships.

None of the town hall meetings produced new ideas about a more flexible and mutually beneficial mode of interaction with industry, as industry interaction was not rewarded by research providers in terms of career advancement.

Question: Who should be responsible for implementation of the decadal plan recommendations?

Discussions about the implementation of the decadal plan centred on the ability to achieve lasting change in terms of science policy and funding for chemistry education and research.

Town hall participants clearly understood that, without a formal ‘body’ taking responsibility for the implementation of the decadal plan recommendations, no constructive change would happen.

They understood that the decadal plan was mainly an instrument to inform government science policy at the federal level.

They therefore expected that the document delivered to government needed to be able to facilitate better understanding of science and chemistry by government staff and politicians, and that it should contain implementable recommendations so that appropriate policies could be formulated.

There was a belief that this plan should be accompanied by a large government lobbying initiative driven by all important sectors of the chemistry value chain: industry, and the higher education, research, and school education sectors.

However, no clear or easy solutions were identified for the issue of funding of the implementation of the decadal plan and the body that should be responsible for it.

Question: If there was a 'Magic Wand' to change for the better how chemistry works and performs in Australia, what would need to be changed?

This 'Merlin' or 'genie' question was asked to break down barriers in thinking about unsolved issues and elicit some new ideas without the issue of funding raising its head. Apart from ideas relating to solving major threats to human life, such as using alternative energy, decarbonising manufacturing processes, ensuring clean water and tackling global warming, some of the ideas voiced were:

Implementation of a four-year degree program to educate chemists. The final year could be a specialty year in which students choose the career they wish to follow—with, for example, intensive concentration on analytical or synthetic chemistry or a research degree (as per current honours degree). This would produce graduates with the specialised skills required by industry. It requires, however, that students know what industry might need.

Development of technology and machines that can carry out a large number of analytical tasks automatically in a very short time as in, for example, the sequencing of genome projects. It has been shown that it is possible to develop such machines, but similar machines are necessary in other areas of chemistry.

Training of chemists in the analysis and interpretation of large amounts of data. This requires people with a deep insight into, and knowledge of, how to interpret data. As routine laboratory tasks are relegated to robotic systems that generate large amounts of data, this interpretive capability is essential.

Technologies for the development of niche synthetic chemicals. There are new technologies becoming available (for example, flow chemistry) which will enable the production of niche synthetic chemicals with very low labour costs; these need to be promoted and developed. Better industry and university collaboration will be required to drive this.

A marketing campaign to increase community understanding of chemistry and careers in chemistry. This would likely lead to chemists being held in higher regard by the general public.

A working body for developing acceptable and agreed environmental standards. In terms of environmental chemistry, we need a working body, like the US EPA, to identify acceptable standards. There are currently only old standards in use, such as fact sheets on chemicals and their effects on environmental and human health. Greater communication with the public is required to progress these.

Conclusions

The town hall meetings provided a forum for the segments of the chemistry value chain to voice and discuss their concerns about chemistry in today's national and global working environment.

There were clear issues identified relating to:

The negative image of chemistry which was seen as a major contributor to the perceived poor attractiveness level of any career that contained the word 'chemistry', 'chemical' or 'chemist'.

This was perceived to lead to poor science literacy of primary and lower level high school science teachers, poor chemistry teaching outcomes and career choices for school students and poor entry level skills of students who enter the chemistry courses at universities. School students make subject choices that allow them to gain good university entry scores and thus avoid subjects that are perceived as difficult—such as chemistry.

This has further knock-on effects. As the breadth of career options has not been clear during the school years, students have to play catch-up to gain sufficient skills in their university courses, once they enter a course that they are eligible to enter due to their entry scores.

The interaction between industry and the higher education and research sector was one of the major issues that the decadal plan is expected to address. However, no constructive ideas that can be implemented fast for economic benefit were coming forward, given the current inflexibility of the current higher education and research and development sector in dealing with industry.

The town hall meeting participants were overall quite pessimistic about the ability of the chemistry value chain to implement any of the recommendations of the decadal plan due to the fact that there is, under current organisational structures of RACI, PACIA and the National Committee for Chemistry, not a single body available that would be able to speak for all sectors of the value chain.

This needs to be addressed as a matter of priority in the decadal plan.

Appendix 13 – Chemistry in Australia: Current issues, critical success factors and opportunities for the future

In-depth stakeholder interview and consultation, June to December 2014

Executive summary

Purpose of the stakeholder interviews

The purpose of this report is to provide a view of the current chemistry community stakeholder operating environment, stakeholder concerns and issues, and an analysis of the stakeholder needs in the chemistry community across its various sectors:

- School sector—teachers and students
- Higher education sector—undergraduate students, postgraduate students, research staff, professors and other teaching staff
- Research sector—employees in research oganisations such as CSIRO, DSTO, ANSTO.
- Private sector companies throughout the chemical industry, biotechnology and pharmaceutical industry: R&D staff, patent attorneys, CEOs and senior executives in companies that are employing chemists or using chemistry based technologies and methodologies, executives and staff in businesses that provide services to private sector companies that employ chemists.
- Government—staff and senior staff and advisors of various federal and state departments and funding agencies.
- Members of the general public—school children and parents, professionals and trades people in various industries.
- International advisors, regulators, funding agencies and finance experts.

A series of 25 to 90 minute in-depth interviews were held covering questions on the interviewee operating environment, issues of concern, interaction between other parts of the chemistry stakeholder community, opportunities, and needs to be met in future to ensure viability of chemistry as a 'business' or a profession.

The chemistry stakeholder operating environment

From the interview information, approximately 600 interview statements were selected that vividly described the working environment of the interviewees and their problems and issues. Using a workshop process an affinity map was constructed with around 45 statements that were representative of all the statements made:

The current operating environment map (Attachment 2) shows what the current operating environment of the major players in the chemistry community looks line and that outlines current issues that lead to suboptimal functioning of the relationships within and between segments of the 'chemistry community'. The map answers the question 'How effective is the chemistry community in contributing to the overall performance and competitiveness of the sector in Australia?'

The map shows clearly that the alignment of the segments of the 'chemistry community' is suboptimal for reaching a common vision and existing linkages are weak and rusty.

Several areas of concern were identified:

- Regional, economical and family disadvantages limit participation of school students in science and chemistry education.

- Students are forced to make career choices early for their future careers in a vacuum of knowledge about chemistry and its benefits.
- Declining viability of Australian chemical companies in today's globally competitive environment makes chemistry an unattractive career choice.
- Awareness about the potential of patentable innovations to drive competitiveness of industry in a global carbon-constrained environment is low in Australia.
- The capabilities of science teachers and principals are critical factors in fostering the uptake of science education by school students and in university.
- The Australian Government's strategic focus is largely not adopted by the research sector and institutional investors, thus leaving Australian industries exposed to increased innovation and future competition from overseas.
- The understanding of Australian chemical companies of Australian research providers is low.
- Small industry companies are disadvantaged in their interactions with R&D providers.
- Traditional university education models limit the value of graduates and research professionals to industry and other employers.
- Early engagement with industry provides new and alternative openings and pathways in an otherwise traditional academic career model.
- Hands-on teacher professional development in chemistry is highly valued but difficult to access by teachers in regional and remote locations.

The chemistry stakeholder needs

*A **'chemistry community' needs map*** (Attachment 3) was constructed from 950 interview statements in the same way as the operating environment map. This map outlines the main areas of needs for the development of requirements and solutions that would eliminate problems that were identified in the operating environment map. The overarching question that the map needed to answer was:

'What are the long term needs of the Australian chemistry community for the next decade and beyond?'

The mapping process highlighted that strategies, systems and processes are needed to support a coordinated approach between government, the research community and industry to increase the relevance and positive impact of Australian chemistry internationally.

Several distinct needs areas were identified:

- All sectors of the chemistry community must develop a long-term forward thinking attitude and implement mechanisms for overcoming the status quo.
- All segments of the Australian chemistry community must lift their vision and learn from the world's best innovators in order to become globally competitive for the longer term.
- All segments of the Australian chemistry community must collaborate to overcome the causes and impacts of chemistry illiteracy and poor image.
- Chemistry education models and materials need to be developed that help teachers to deliver educational and chemistry literacy benefits to children of all ages and backgrounds.

- The prospects and benefits of the likely future career paths of the next two decades must be defined and communicated to stakeholders.
- The capabilities of Australian research providers need to be strengthened substantially to enable them to become the preferred R&D partners for both Australian and international companies who seek high-end innovation.
- Improved and more affordable, effective and efficient R&D collaboration mechanisms are required between industry and research providers in Australia.
- Chemistry research translation mechanisms need to be developed that are viable and advantageous for all participants.
- New higher education models are required for providing chemistry graduates and postgraduates with the skill sets demanded by the industries of the future.
- Government agencies and industry need to develop more collaborative rather than the current adversarial mode of interaction for achieving a quicker realisation of regulatory benefits.

Actionable requirements

From the stated issues, problems and broad stakeholder needs, 39 distinct actionable requirements were generated which were then ranked by a representative sample of the interview matrix on their importance and satisfaction with the current status of implementation.

From the mean importance and satisfaction ranks an opportunity index was generated that was then used to rank the requirements on their opportunity index with those with the highest opportunity index at the top of the ranking table (Table 1). The higher the importance rank and the lower the satisfaction rank, the higher the opportunity index of a requirement. This allows us to identify those requirements that, if addressed will lead to high satisfaction of stakeholders an high impact of potential solutions.

Most of the requirements were identified as ‘must haves’ or ‘basic’ requirements of the stakeholder segments. This shows that there is very little satisfaction with the current state of implementation of solutions to address those requirements.

Most of the top ranked requirements related to high level issues, as well as lack of international best practice in terms of policy and process in government, education, innovation and interaction between the various stakeholder segments. These problems were seen as very important shortcomings that stifle Australia’s ability to compete in chemistry related pursuits globally.

The top requirements, based on opportunity rank, relate to:

- improved international best practice in government science and innovation policy making
- improved collaboration between stakeholder segments to achieve better outcomes
- improved efficiency of research funding process
- better collaboration between stakeholder segments to overcome chemistry illiteracy and the current poor image of chemistry
- improved and equitable teacher education, professional development and education materials, especially for primary school teachers and those in disadvantaged areas

- strengthening the capabilities of research providers to stay relevant and internationally attractive to research funds investors including industry nationally and internationally
- improvements in the higher education process of chemistry students to provide clearer and more transparent career opportunities that will allow employment in the future in a more diverse employment environment
- improvement in the interaction between industry and the research sector in terms of intent and in process.

Conclusions and next steps

The ranking of the requirements reflected the need for remediation of the suboptimal linkages between stakeholder segments of the chemistry community and for strategies and processes for improving the coordination and alignment between the segments for an ultimately increased impact of Australian chemistry in the long term.

The opportunity index is one way of ranking the requirements. The ranking is aligned with the issues identified in the operating environment map as well as the stakeholder needs map.

In the Kano diagram (see Figure 1), all requirements are located in the must-have quadrant or under the linear performance line. This means that the operators in the chemistry value chain feel strongly that they currently do not get what they need, or that what they get is sub-optimal in a world's best practice context.

However, it is obvious that neither the chemistry community as a whole or any of its stakeholder segments have the capability or resources to address all of them.

The dilemma is that all requirements will need to be met over time for Australian chemistry to become one of the top global players instead of playing the game 'who is the tallest midget' but the resources and capabilities for achieving this are currently limited.

The next step will need to be, after evaluating the two surveys (chemistry teacher survey and chemists in government survey) and the requirements derived from the town hall meetings, to define also how vital and how urgent each requirement is for achieving the overall vision for chemistry.

Vital requirements should be those that need to be met to ensure the vitality and the survival of chemistry as a 'business' in Australia. Urgent requirements are those that ensure that chemistry can have enough resources to live to tomorrow. After having decided which of the urgent and the vital ones should be addressed the question of how implementable each of them is needs to be addressed, such as considering cost, people available, capabilities of the various stakeholder segments and the availability and appropriateness of metrics to measure progress.

The process for arriving at a number of implementable requirements and costed options for solutions will include the construction of a number of Kano plotting graphs and Pareto diagrams

In the end decisions will need to be made on a limited number of implementable requirements that will need to be resourced and their progress measured against international benchmarks. This then will also require a good and well-structured benchmarking process.

Introduction and background

The Chemistry Decadal Plan 2016-2025 began in April 2014 and the stakeholder consultation for this project began in June 2014.

The aim of wide stakeholder consultation was to identify the issues and problems the chemistry community is currently facing in the current competitive global operating environment, define the requirements of stakeholder segments and arrive at opportunities for improvements, and finally identify the critical success factors that will enable the chemistry community to make step changes to be more competitive in the future.

Three distinct approaches were used to reach a wide stakeholder audience:

1. In-depth interviews throughout the chemistry community, the subject of this report.
2. Two specific targeted electronic surveys of the chemistry teaching community and chemists in government funded institutions. The results of these will be subject of a second report.
3. A number of town hall meetings across the country with school teachers, with students and research and teaching staff in higher education and research organisations, and with members of the corporate sector. The outcomes of these will be reported in a third report.

The analysis of these consultations was through approaches widely used in new product and service development and strategic planning throughout industry and government.

Purpose of this report

The purpose of this report is to provide a view of the stakeholder operating environment, stakeholder concerns and issues and an analysis of the stakeholder needs in the chemistry community across its various sectors:

- School education sector—teachers and children
- Higher education sector—undergraduate students, postgraduate students, research staff, professors and other teaching staff
- Research sector—employees in research organisations such as CSIRO, DSTO, ANSTO.
- Private sector companies throughout the chemical industry, biotechnology and pharmaceutical industry: R&D staff, patent attorneys, CEOs and senior executives in companies that are employing chemists or using chemistry based technologies and methodologies, executives and staff in businesses that provide services to private sector companies that employ chemists. The type and size of private sector companies providing interviewees ranged from large multinational companies with several thousand employees, SMEs with less than 200 employees to small Australian companies and even one-person service providers.
- Government—staff and senior staff and advisors of various federal and state departments and funding agencies.
- Members of the general public—school children and parents, professionals and trades people in various industries.
- International advisors, regulators, funding agencies and finance experts.

This report will be used as the basis for further discussion and consultation with members of the chemistry community and, together with the two other reports mentioned above, provide input into the recommendations of the Chemistry Decadal Plan and its implementation plan.

Methodology

In-depth interview process

The interview process followed an established process used in new product and service development to identify customer issues and requirements in the context of developing new strategies for meeting customer while becoming more competitive in the market[1].

Stakeholder matrix

To ensure that the breadth and depth of the chemistry stakeholder community was covered adequately, an interview matrix was constructed that contained all its major segments, as identified in the background research. Within each segment a number of individuals were selected who had sufficient expertise within their own sector and in many cases, in adjacent sectors, to comment and provide their input via the interview process. A list of approximately 200 individuals was used to establish contacts and set up a balanced interview matrix. Ultimately 40 in-depth, 25-90 minute long interviews were held, either by visiting the interviewees in their place of work or by phone. An additional 20 follow-up interviews were also held.

Interview guides

For each interview a set of five questions with additional prompts was used to ensure that a common and structured framework was followed throughout all of the interview. The interviews were recorded and transcribed. It was made clear to the interviewees that their interview recordings and transcripts were to be kept confidential to ensure frank conversation. An example of an interview guide with its questions and prompts is included as Attachment 1 at the end of this appendix.

Extraction of issues and needs

The transcripts were then used to extract statements relating to issues and problems in the current operating environment of the interviewees and to identify their needs and requirements for future improvements.

The interviews were recorded and transcribed and the transcripts were then used to draw out common issues and requirements. The methodology used for the evaluation of the interview information was based on that described by Burchill and Hepner Brodie in their 1997 book 'Voices into Choices'[2] and Karl Ulrich of the Wharton School at the University of Pennsylvania in 2003[3]. This

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[1] Ulrich, Karl and Steven D Eppinger: Product design and development, 2011
[2] Burchill, Gary and Christina Hepner Brodie.: Voices into Choices. Joiner 1997
[3] http://opim.wharton.upenn.edu/~ulrich/documents/ulrich-KJdiagrams.pdf 2003

method uses KJ diagrams[4] that focus on language data rather than numerical data. The method is named after Professor Jiro Kawakita from the University of Kyoto. It is especially useful for problem and needs identification and for developing requirements for solutions to problems. Consequently this method has been widely used in new product and service development. One of the distinct advantages of this method is that it can identify issues and relevant requirements quickly even with a small set of interviews.

From the interview information, approximately 600 interview statements were selected that vividly described the working environment and related issues while a further c. 950 statements were collected relating to the clearly stated needs of interviewees in their operating environment. These statements were then analysed in two, one-day workshops, where the large numbers of statements were reduced to two KJ maps with around 45 statements each that were representative of all the statements made. The two KJ maps were:

1. The current operating 'environment map' showing positive strengths of the current operating environment in the chemistry community and outlining current issues that lead to sub-optimal functioning of the relationships within and between segments of the 'chemistry community'. This map answers the question 'How effective is the chemistry community in contributing to the overall performance and competitiveness of the sector in Australia?'
2. A chemistry community 'needs map' showing what the expressed needs of the different segments of the chemistry value chain are. These needs are then used to identify and construct strategies for long-term viability and competitiveness of the stakeholder segment and the complete stakeholder community in the global context.

The two maps are at presented as Attachments 2 and 3.

Requirements generation

The interviewees were selected on the basis of an assumed deep knowledge and experience in their segment of the chemistry community. The issues, problems, and shortcomings described by interviewees were translated into an actionable requirement that could then guide the development of implementable solutions.

To develop actionable requirements for implementable solutions the following process was used. An example of how this approach is actually implemented is shown in the text box below.

Taking one operating environment statement and one needs statement (in no particular order or preference) the key issue that ties these two statements together is defined.

To address this key issue, which is usually having a negative impact on what the chemistry community wants to achieve in the long term, a number of requirements were then developed.

Going through a list of 50 to 60 operating issue statements and the same number of needs statements from the two maps, approximately 80 to 100 requirements were defined. These then

[4] A good description of the method and its differentiation from affinity diagram methods is given here: http://www.isixsigma.com/tools-templates/affinity-diagram-kj-analysis/effective-use-special-purpose-kj-language-processing/

were grouped into logical groups of similar requirements, which were then rephrased into a group of 39 specific requirements.

Requirements generation
Interviewee needs statement Australia needs to adopt world's best practice in industry processes and policy making,
Interviewee operating environment issue statement Negative community and parent attitudes to science and education limit children's future prospects
Key item Scientific illiteracy has a broad negative impact on several sectors in Australia. There is unawareness of the impact of science illiteracy on policy making, strategic planning and process implementation in industry.
Actionable requirements All children must have a specific minimum knowledge of chemistry when they leave school. All children must at least meet the minimum international competence benchmark in STEM subjects (including chemistry) in all assessment years. The science literacy of politicians at all levels must be increased. Chemistry literacy of decision makers in private sector companies must be increased for better strategic planning decisions on infrastructure and process upgrades.
Requirements and metrics Numbers of school students meeting international benchmarks, numbers of politicians in parliaments and company executives in decision making roles with science degrees. Numbers are increasing over a specific timeframe (decade).

This process of translating the 'needs' stated in interviews in the context of the issues is necessary because not every 'need' that an interviewee voices is automatically a requirement. For example, if an interviewee states that 'the government should keep tariffs up so that imported chemical products are more expensive than locally produced ones' and a context issue statement says 'The awareness of Australian companies about the need for innovation is low' this does not mean the requirement statement should be taken at face value, which would then read that 'import tariffs should be maintained to allow the low awareness status to persist'. The key issue in this context is competitiveness or the lack of competitiveness due to barriers relating to innovation. Requirements in this example need to address this key issue and how to survive without tariffs.

Requirements ranking survey

The list of 39 requirements was then converted into a survey format using a SurveyMonkey web based survey format and sent to the interviewees and a wider cross section of the chemistry stakeholder community. A stakeholder email list, segmented and balanced according to the original interview matrix segment proportions was used to send the web link to the SurveyMonkey survey.

Each respondent was asked to rank each of the requirements on:

- importance for them in their operating environment—from Zero (no importance at all) to 5 (extremely important)
- satisfaction with how well the requirement is currently met—from Zero (not met at all) to 5 (completely met already).

From the email list of 300 names, 59 full responses were received. For each requirement a mean ranking score was calculated for both importance and for current satisfaction on how well it was met.

Based on the mean importance and satisfaction scores an 'opportunity' score was then calculated for each requirement. This allowed us to identify those requirements that had high importance scores as well as low satisfaction scores and to rank the requirements according to their 'opportunity scores'.

Requirements categories

Requirements that are used for developing solutions to important issues can be allocated to one of four categories, based on Kano5:

1. Requirements for solutions that must be met, also called "must-haves" or "threshold requirements". They are specific requirements that will result in considerable dissatisfaction if they are not met. They are high on the importance ranking scale and low on the satisfaction ranking scale. Often they are not even mentioned because stakeholders assume they are already met in current solutions—because the provider of the solution should know how important these requirements are. Examples for must-haves are functioning brakes in a car, where buyers at purchase of the car don't even ask whether the car has any brakes, they are assumed to be there and fully functioning. However, if the brakes are not functioning properly, satisfaction is very low. These requirements are those in the bottom right quadrant of Figure 1, located below the line labelled 1.
2. One-dimensional requirements, where satisfaction rises proportionally to the importance of the requirement. The more mileage a car drives with a given amount of fuel the better, or the less fuel per 100km the better. Competitive advantage results from delivering either higher quality, more features, lower cost, more speed etc. for the same or similar inputs than competitors. Dissatisfaction arises from not meeting minimum standards. These requirements are usually fully understood by stakeholders and can be voiced by them in terms of metrics. These requirements usually cluster along the diagonal line labelled 2 in the upper right quadrant of Figure 1.

[5] A good summary of how a Kano model is used in new product and service development can be found here: http://www.kanomodel.com/discovering-the-kano-model/

3. Delighter requirements, that would provide a point of positive differentiation compared to competitors. Often these are requirements that stakeholders have not thought about before they are translated into desirable solutions. Initially they are not seen as of high importance (e.g. air bags in cars). The first driver airbag was a “delighter”. Eventually all delighters become linear, one-dimensional requirements (the more airbags the better) and later to must-haves (new cars without airbags don’t find buyers). These requirements are located in the top left quadrant in Figure 1 and above the line labelled 3.
4. Requirements to which there is an indifferent attitude. Nobody thinks they are very important and nobody cares how well they are met because they are not important. Developing solutions for something above the line labelled 1 in the lower left hand quadrant of Figure 3 is not productive and not cost-effective.

Kano diagram analysis

A Kano diagram-based analysis was then used to plot each requirement into diagrams based on satisfaction vs importance, and to further on ease of implementation vs urgency.

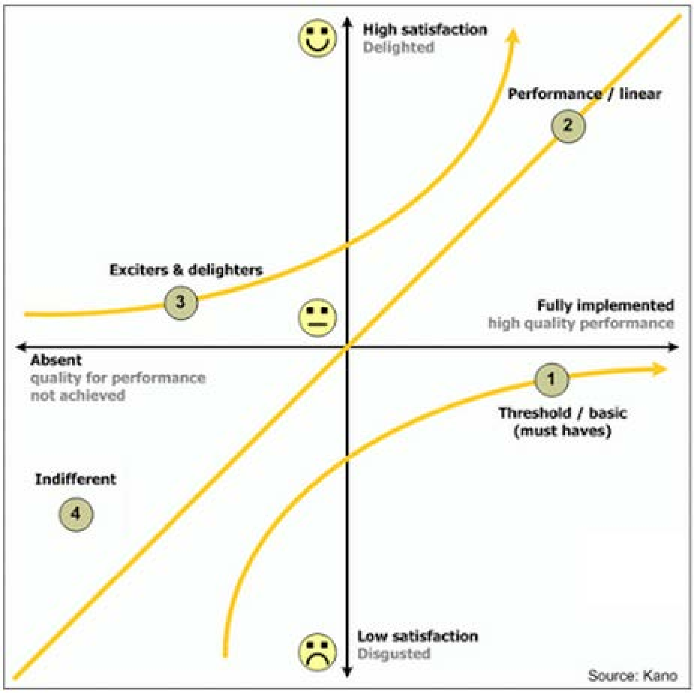


Figure 1: Typical Kano diagram

To prioritise these requirements, further differentiation was needed. Therefore additional scoring and ranking was performed by the Chemistry Decadal Plan committee on:

1. Urgency to implement effective solutions for each requirement (Score 1 very low urgency, 2 = low, 3 = moderately urgent, 4 high urgency and 5 = extremely urgent).

2. Ease of implementation of solutions for each requirement (Score 1 extremely difficult to implement, 2 = difficult to implement, 3 = moderately easy, 4 easy to implement, and 5 = very easy to implement).

Note here that “urgency” is not “importance”! The degree of urgency reflect the need to act immediately to implement some action if we want it to succeed. Ease also reflects a new aspect to the process. There may be numerous things we can do with little resourcing or funding, but these actions may not resolve “important” issues. For example, “delighters” might be exciting and easy to implement but may not help the sector. An example might be getting a famous Chemistry Nobel Laureate to come to Australia.

Plotting the requirements into a new Kano diagram in which the vertical axis was the mean “ease of implementation” index and the horizontal axis the “mean urgency” index of each requirement, resulted in a wider spread of the requirements in the diagram (Figure 2).

In summary, to try and prioritise the 39 requirements identified by the chemistry sector, they were first ranked in terms of “importance” and “satisfaction”. This allowed some to be discarded or lowered in priority. However, many requirements had similar rankings on this basis, which would make ultimate implementation difficult to carry out. By replotting the requirements in terms of their “ease of implementation” and their “urgency”, better differentiation was posssible.

These 4 characteristics were then combined into an overall “attractiveness” index, based on the opportunity index, mean implementability and mean urgency of each requirement, hoping to find a best fit rank for each requirement that would ensure that all of the most important, urgent and currently poorly met requirements could be easily implemented, and that expenditure of effort and resources on hard-to-implement or less important requirements could be avoided. However, this index by itself was not the most useful one as it provided results that were less informational than those obtained via the two Kano diagrams

The Kano-based re-ranking requirements resulted in a number of new lists that are provided in Tables 3 to 9 as “must have requriements”, “exciters” and “delighters”.

These tables will be of importance for implementation of decadal plan strategies and guide the sequence of implementation.

Project findings

The current operating environment

The in-depth interviews attempted to find an answer to the overarching question:

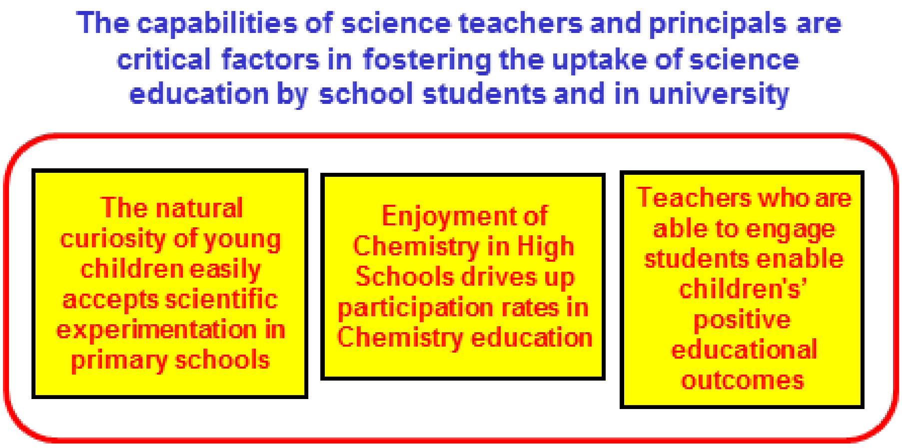
"How effective is the 'chemistry community' in contributing to the overall performance and competitiveness of the sector and Australia?"

This question not only attempted to identify important issues and problems within each of the stakeholder segments but also where the links between the segments appeared to be not functioning optimally.

A complete map of the operating environment issues is provided as Attachment 2.

The following distinct issues were identified:

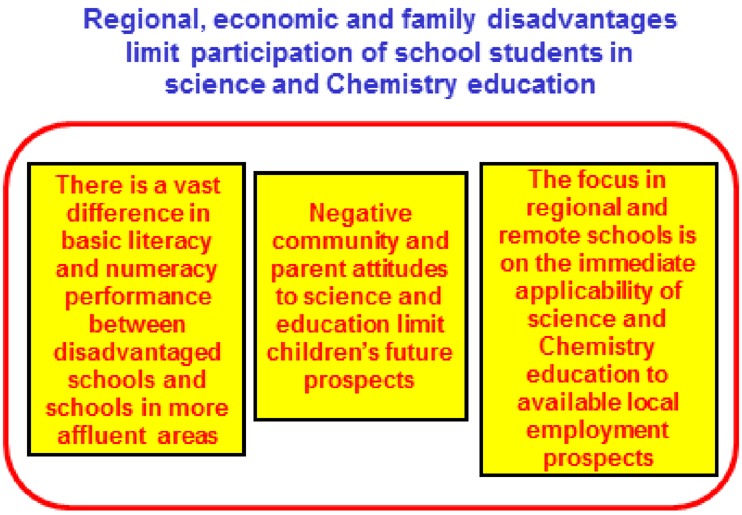
Enjoyment of learning and relevance is key



It was clear throughout the interviews that small children in the early years of primary school were very open to participating in any science experiments. They loved explosions, measuring and also accepted that sometimes things did not work out as expected. However, in the middle and later years of high school relevance of experiments and theory needed to be clear for enjoyment to persist. Rote learning of the periodic table was a major turn-off, even for students who had no problems with maths and was given as a reason for de-selecting chemistry in favour of other subjects. Students who progressed to chemistry and chemistry related subjects in university had an awareness that the quality of teaching chemistry in school had a major influence on their career choice.

There is a clear indication that the uptake of chemistry subjects in schools has a lot to do with the quality of the school teaching staff and of the principal. Whilst respondents from some schools indicated that in their schools the majority of year 11 children chose chemistry, in other schools they were actively discouraged from taking it up because it did not fit with the available employment opportunities with "chemistry fit" in the area the school was in.

Any disadvantage limits the uptake of chemistry in school



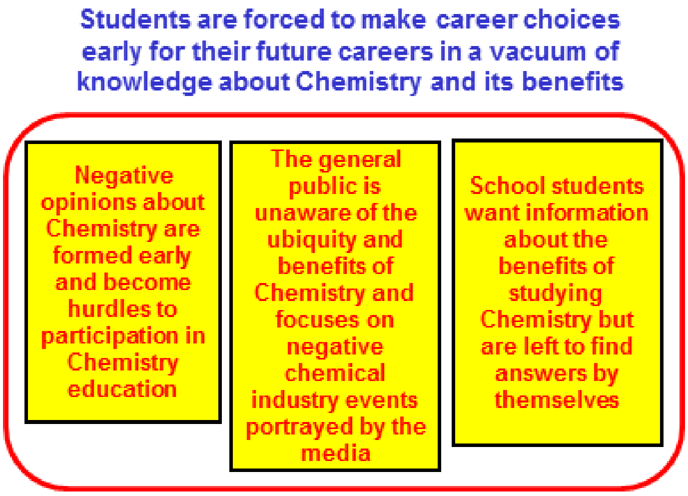
Although children in early primary school show natural curiosity in many things including science based pursuits in school, any disadvantage due to their home environment such as alcohol, violence, parent illiteracy and poor parent educational background, drugs and economic disadvantages, appeared to have an impact on their literacy and numeracy performance and the children's ability to phrase questions and discuss what they see, all requirements for the beginnings of being able to enjoy science.

Poor parent educational background additionally turned children actively off science and the preference of parents to provide children with 'things' instead of knowledge appears to lead to a lack of interest in science in the children and to frustration and disenchantment of the teachers – provided that there is no active push for science by the principal.

In regional and more so in remote schools there is still a focus of teachers and the parent community to expect girls to take up biology to find employment as nurses or in other health professions and boys physics as it supposedly fits better with trades related employment. Chemistry in these schools appears to be the poor cousin that nobody knows what it is good for.

There was, amongst teacher interviewees, parents and children, the view that subjects chosen in high school had to fit with what jobs were currently available in the area such as in mining, farming, fishing, steel works, building and construction etc. If school leavers traditionally found jobs in mining operations then there was the expectation that those types of jobs would always be there in the future and no new learning was required beyond that type of employment opportunity.

The opinion about what chemistry is and does is formed very early in life and is long-lasting.



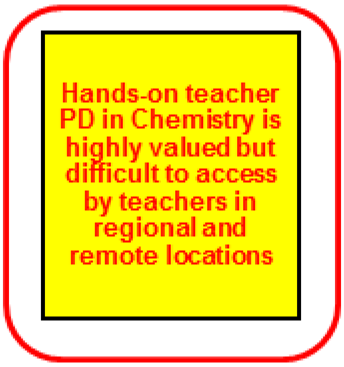
Children as young as six years of age have already formed a negative opinion about what a chemical is, something poisonous and ready to kill people, and for many this is what they will think and believe for the rest of their lives, even though some of them may study chemistry subjects in high school to keep their options open and in university to achieve specific professional qualifications.

There is a great vacuum of knowledge throughout the general public and in most professions about how chemistry fits into society's daily lives, the benefits that are derived from chemistry. Mostly negative connotations are mentioned such as poisons, pollution, GM crops, global warming, and weapons of mass destruction. There is no perception even amongst many professionals about what opportunities might open up in the future in nanotechnology, materials science, biotechnology, in medical science and many other professions.

It was found that there is very little information available to parents and children as well as schools and teachers so that they are able to provide some meaningful guidance to school students about the benefits of chemistry literacy, selecting chemistry subjects in the later years of high school.

In particular, there is a lack of information about the cross-disciplinary importance of chemistry.

Although many teachers may be aware of the importance of chemistry in general, they voiced a specific need for professional development in chemistry.

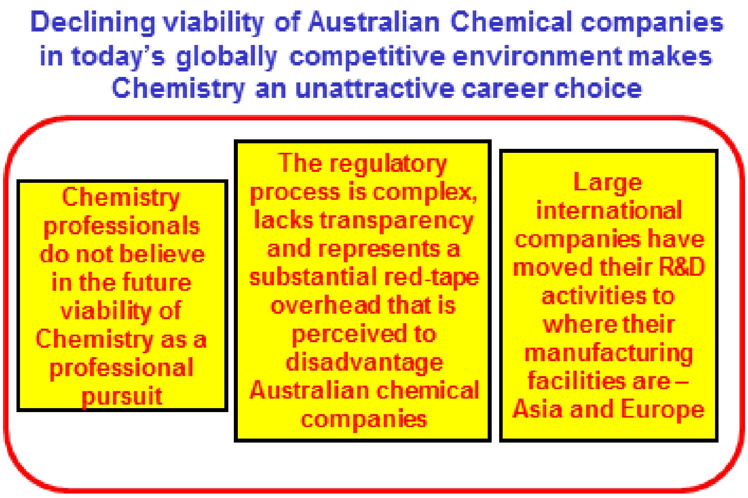


Especially teachers in remote and rural locations find it difficult to access professional development opportunities. The tyranny of distance makes it more difficult for them than for teachers in metropolitan schools and larger regional centres. Even though some universities have campuses in regional areas they often do not provide science and especially chemistry related courses and thus there are no university lecturers or researchers available to provide regional and rural professional development or be the focus of science teacher networking opportunities.

An increased focus on risk management and WHS regulations and often poor infrastructure for science teaching makes it more difficult for disadvantaged schools.

In comparison schools in metropolitan areas, and those especially close to Group of Eight universities have fewer difficulties in accessing chemistry professional development and therefore in those schools the uptake of chemistry in year 11 and 12 appears to be higher than in regional schools.

Chemistry is seen as a poor career choice in a declining industry– even by chemists

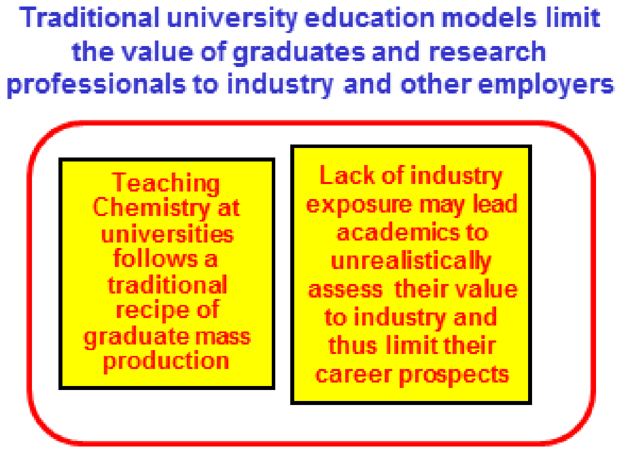


All interviewees in industry, academia and research had a pessimistic outlook for the Australian chemical industry as employers of the future. It was common knowledge that the majority of large industry companies globally had shifted some of their operations, including at least some of their R&D laboratories, to Asian countries. Many surviving global and multinational companies operating in Australia have over the last two decades have reduced their R&D efforts in Australia. The majority of Australian chemical companies are small by international standards and their R&D efforts therefore are small also. This portraits a grim picture to the general school leaver and their parents.

There is a lack of large global Australian chemical companies – CSL is perhaps the biggest and is a biotech company.

The perceived negative outlook for Australian chemical companies and their perception that the regulatory processes for registration of chemicals in all industries, the red tape related to interstate transport, environmental and WHS regulation disadvantages Australian industry in favour of importers from other countries. In the context of regulatory processes industry interviewees were feeling distinctly let down by government agencies which were perceived as less than helpful.

Universities are set in their way of delivering education outcomes



When students transition from high school to university, most of those enrolling in chemistry courses have chosen a pathway leading to a professional qualification such as medicine, veterinary science, engineering etc. that requires at least one year of science or a BSc qualification.

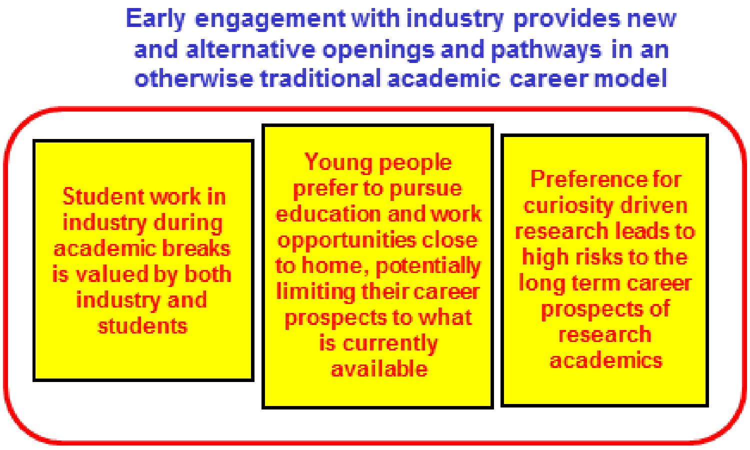
Most of these students will not become chemists and, of the approximately 2000 students who start in a year one, only 80 or 100 may end up becoming chemists. Some of the interviewed chemists were critical of the one size fits all teaching of these large numbers of students comparing this to conveyor belt education. They expressed doubt that what was taught to many of these students was not really applicable or at least the students did not see any relationship with first year chemistry and what they would need as a future medical practitioner, dentist or agricultural scientist.

Achievement of a BSc qualification did not appear to automatically give graduates a good perception of what they could do with such a degree and they certainly did not see all the potential opportunities and the transferability of their skills into additional educational pathways.

In the UK, there is a strong emphasis on transferable skills—science graduates are highly sought after in other sectors.

A very common likely pathway was seen to lead to further postgraduate qualification as either a Masters or PhD qualification with transition subsequently to a position in academia and research. This pathway was seen as a preferred option that was well understood in terms of what was required. What was not well understood, were the limitations in terms of a career security and the difficulty to 'stand out' as an early career scientist amongst the many that attempt this career path.

Young graduates as well as early career researchers had an overly optimistic assessment of their value for industry and were looking for R&D positions that were more advanced than their experience in working at fast pace and in teams. Not finding a job that had "research" in the job description was not easy and these young people became quite disillusioned with their career prospects. This was especially prominent amongst those on some of the ARC Future Fellowships who saw themselves as too old for industry to get started there and with no hope of a more permanent position in academic research.



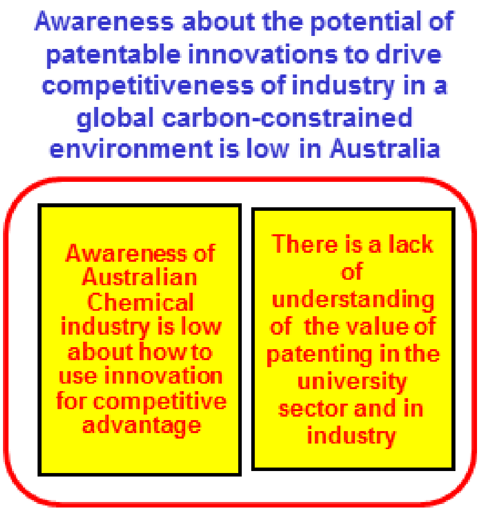
The fact that during higher education chemistry students received little or no practical work experience in industry was seen as a shortcoming of university higher education of chemists and potentially chemical engineers in some cases. Students who did work with industry companies during semester holidays were valued by their employer during their stay but the students also valued the opportunity given to them.

However, it was seen as difficult for small companies to invest the necessary training time into a student worker who would leave after a short time. For some students the opportunity translated to employment later in the company they had worked in during their studies.

Most of the young interviewees, whether school students or university students and young postgraduates were looking for employment opportunities close to home.

The fact that the traditional university teaching models do not require substantial time of students in industry to gain an overview of what chemical industry and other industries do, the constraints and opportunities that exist was seen by industry as a shortcoming of the traditional chemistry education model of the higher education sector.

The need for and the drivers of innovation in the chemical industry is not sufficiently understood



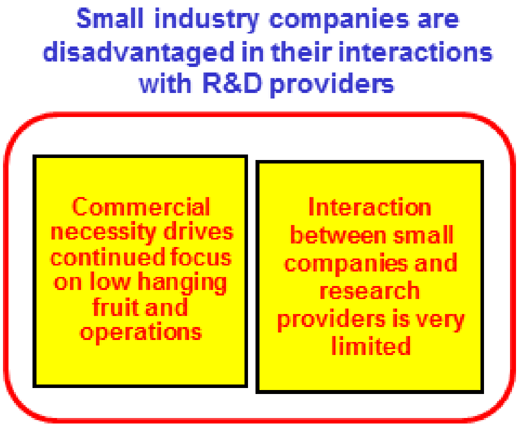
Interviewees largely, except for those from Europe and from the finance sector, underestimated substantially the degree by which the chemical industry globally and in Australia will be carbon constrained in the future, and especially the severity and the timeframe predicted for having to make effective adaptations to operations through step change innovation in both processes and through introduction of new to the world products.

Innovation opportunities were seen largely in process improvements to cut costs, downward changes to wages, outsourcing manufacturing to Asia, mergers with larger international companies, and the hope government would re-introduce tariffs. New product development was seen by several interviewees as changing of formulations rather than development of new molecules and compounds for new markets.

The value of creating new IP that is commercialisable is not only not fully understood by at least some of the SMEs but also in research organisations who have several objections to patenting, such as the cost of it, the lack of reward, recognition and promotion opportunities for doing it in academic institutions, limited translation pathways for chemical IP and the long time to registration and to market.

The understanding of the need to patent and depend on IP and commercialisation of IP has been much higher in interviewees from European countries and the USA as well as from large multinational and global companies.

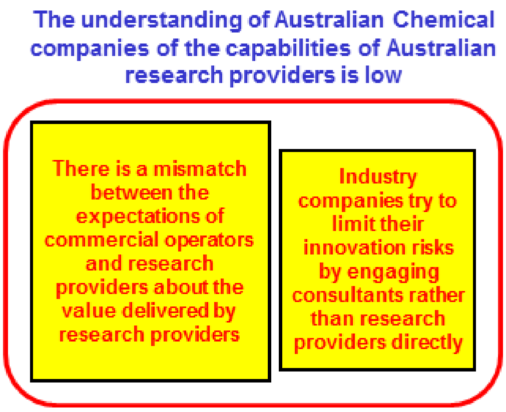
SMEs are disadvantaged in getting help from R&D providers



As the cost of a researcher in a university or CSIRO is in the order of $150,000 to $180,000 per annum and other R&D costs add up to substantially more and the funds need to be spent before some of it can be recovered via R&D tax concessions, it is understandable that innovation seems to happen mostly in mid-sized companies that have some consistency in spending on innovation and utilising R&D taxation benefits from year to year. However, it requires that these companies are profitable enough to spend on innovation and that they spend on R&D that is short term and delivers a return on investment fast. This type of innovation tends to be low risk and “low hanging fruit” and therefore is of low interest to universities, and especially the large research focused universities in the Group of Eight.

Consequently, some universities do not have any contacts with any of the smaller chemical companies or companies that could use their research expertise in the chemistry related space. Some researchers even do not want to have any contacts with them as they feel their problems are too mundane to deserve their input.

The benefit of working with research providers is not clear for many companies



Overall research providers such as CSIRO and especially universities, besides being perceived as expensive are also perceived as slow and working at an academic rather than a commercial pace. One of the causes may be that the research provider organisations, and especially universities, are not providing transparent costing to the industry client and are not communicating how high cost will translate into value for the industry companies. Especially the cost of high end research infrastructure and equipment acquisition and maintenance is not communicated sufficiently in context with the ability to access this equipment and the expertise of running it at a fraction of the cost that the research provider pays. Just providing a summarised multiplier to quotes is not seen as sufficient for potential clients.

Whilst large companies have both the machinery and also deeper pockets for funding R&D and managing risks and failure of projects, SMEs generally have little fat to pay for R&D. Large companies frequently pay consultants to help them with process improvement innovation and a number of large consulting firm specialise on contracting to large chemical companies. However, they largely do not take on SME clients because their risk profile makes them unattractive. This leaves only small consulting firms and research organisations and government laboratories such as the CSIRO as R&D providers for SMEs in Australia.

It was made very clear by industry interviewees that they carefully assessed the risk of engaging with research organisations in terms of time to delivery, costs and probability of project failure.

Overall, especially SMEs have a poor visibility of the research capabilities of any of the research organisations in Australia. Many research provider websites appear to be more targeted to students and researchers than to industry and they do not provide sufficient and easily accessible information for industry clients on potential services to different industry sectors, equipment available, and points of contacts.

There is limited alignment of research organisation and industry goals with government goals

There is clear evidence that the Australian research sector has a more long term view of research and the likely research results needed in a future carbon constrained world. In fact, there is evidence of a clear misalignment of the research sector to current Australian government policy. Consequently the research sector looks closely for guidance towards the long-term strategic directions of other countries, especially Europe, USA and Singapore, both at the country level and at the overarching regional level such as the EU level.

Research sector interviewees were very critical of both the lack of awareness of government agencies, politicians and some of their advisors of strategies in place in leading innovating countries and by international investors and the lack of long-term non-partisan policy that would address necessary strategies to adapt to a severely carbon constrained and increasingly competitive global environment of all sectors of the chemistry stakeholder community in the near future.

There was a disenchantment with the level of understanding, the will to change in both the Australian government sector and in industry and due to poor financial capability of the Australian chemical industry, with the ability in Australia to address the challenges of the future. Consequently some interviewee in the research sector said they had basically "given up on the Australian industry" and focused on finding collaborators in other countries with the aim of commercialising their IP overseas instead of in Australia.

The chemistry stakeholder community needs

During the interview process Interviewees were specifically asked how they would like to see the chemistry stakeholder community change in the future to make survival for their part in it easier.

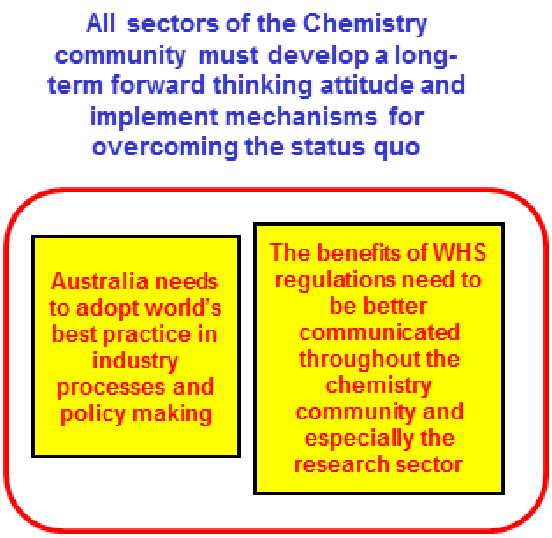
The analysis reflects to a degree the issues identified in the operating environment analysis. However, interviewees took a broader and more helicopter like view of the stakeholder community needs and defined their needs with less of a short-term focus than when they described their issues and problems.

Answering to the question "What are the needs of the Australian chemistry community in the next decade and beyond", the community response could be summarily defined as follows:

"Strategies, systems and processes that support a coordinated approach between government, the research community and industry to increase the relevance and positive impact of Australian chemistry internationally".

The following groups of overarching needs were identified for which specific requirements were defined later for future solution development:

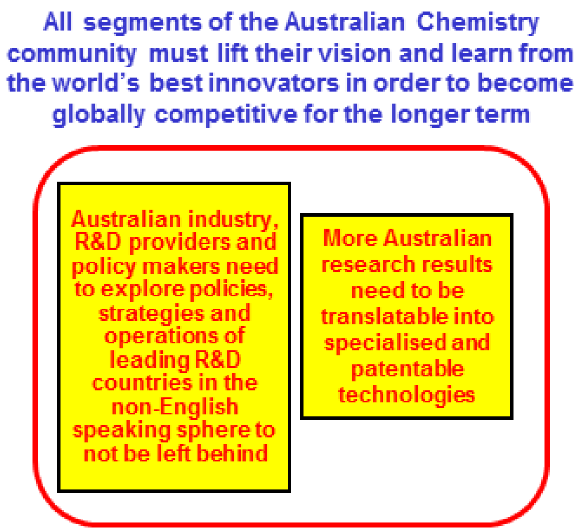
All segments of the chemistry community must develop a long-term forward thinking attitude and implement mechanisms for overcoming the status quo



One of the most fundamental needs across the stakeholder segments was that government policy making should have a long-term and non-partisan focus and develop strategies in line with those already existing in Europe, the USA and other advanced countries that focus on staying or becoming more competitive in a severely carbon and water constrained operating environment .

In terms of Australian policy, especially a long-term energy policy was seen as essential that takes into account existence of already defined strategies in competitor countries and the need for Australian industry to stay competitive, and for their R&D supply organisations to deliver viable solutions that will be commercialised in Australia and not overseas.

The community did not believe that Australia was operating at best practice level in several stakeholder segments, government in regulation, industry in industrial processes, the research sector in the use of WHS regulation application and research efficiency. Therefore the need was expressed to develop a more long-term and global best practice focused approach throughout the stakeholder community.



Many interviewees expressed the need to not only look at the innovation strategies of Australia's traditional English speaking countries such as the UK, Canada and the USA but to also explore and analyse how the long-term innovation strategies of European countries are aligned with their own and other European and EU long term vision and goals.

The value of being fully aware of the innovation strategies of several Asian countries was thought to be in early identification of where new technologies would arise that would be detrimental to the competitiveness of Australia, as these countries were not only investing large amounts of funds in innovation but also were increasingly developing long-term energy, greenhouse gas policies and other related policies.

Many of interviewees stated that Australian companies were not sufficiently aware of the need to produce new to the world and high tech products that would be different to what is produced in other countries and protect the IP of these new technologies and solutions.

They also did not believe that the Australian Government and its agencies were giving industry sufficient help to produce these solutions as they were focusing on short term political goals rather than on long-term goals that would benefit the country in a future carbon constrained environment. For example the need to have stronger building and construction policies and guidelines and enforcing them would lead to increased innovation in building products that were appropriate for the Australian environment but also for other countries with similar environments. Comparisons were made with Germany where building codes and regulations were driving building renovation and building and construction material innovation. Industry interviewees were expressing a string need for not only stronger regulation but also enforcement.

The causes of poor science literacy need to be addressed to improve high level strategic planning

As the severity of chemistry and science illiteracy was seen as very high and the impact of this illiteracy on all levels of society was seen as hindering Australia's competitiveness in the next decade and beyond, most interviewees expressed the need for solutions to address this issue.

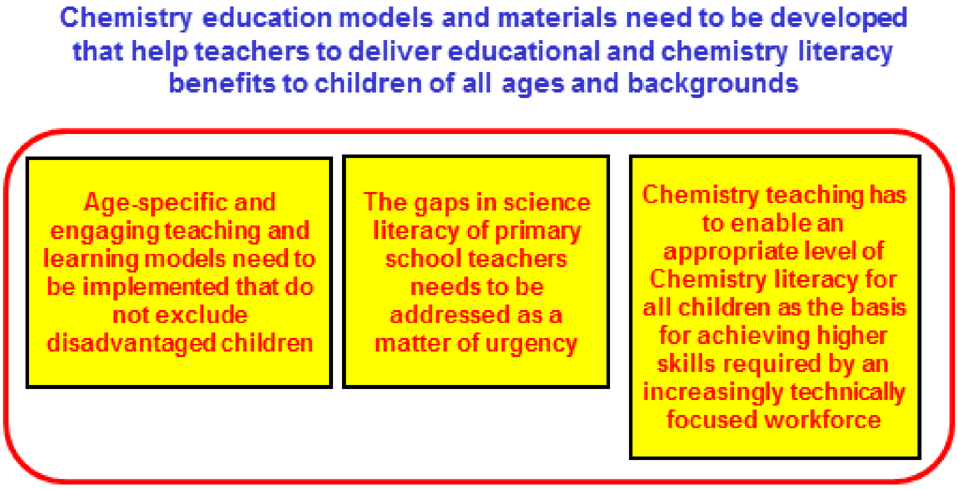
However, they believed that the problem was so big that it needed strong action of all segments of the chemistry stakeholder community. It was seen as insufficient to leave chemistry education to just the teachers in school or the chemical companies to show good governance.

There was a strong need expressed for all segments of the stakeholder community to work together and convey a common message about what chemistry is, what it does today and what it will do in the future, its value to individuals and for the country and the global community.

An area of concern was the poor attitude many parents expressed relating to the value of science and chemistry for the future careers of their children. As the parents are interested in seeing an immediate application of chemistry to a specific "job", the limited knowledge of both teachers and of the tertiary sector about future "real jobs" using chemistry did not convince them to change their negative attitude to science and chemistry.

As this attitude of the parents appears to be perpetuating in the attitudes of their children interviewees thought that there was a need to communicate to parents, children, teachers, schools and the media what the jobs of the future might be that will need chemistry knowledge and why there is a value in learning and studying chemistry.

Chemistry must be made more fun in school



The interviews clearly showed that both school students and teachers needed more teaching materials and models that would allow chemistry to be taught and learnt in a more fun and engaging way. This applies especially to schools that are disadvantaged in terms of distance, economic background of children or for other reasons. Ageing infrastructure of science class rooms was seen as detrimental to make science fun as only limited resources were available.

Schools near the Group of Eight universities were seen as privileged as they had usually already established relationships with science faculties or through the teaching courses. However, schools away from these types of universities have to make substantial efforts to provide their students with similar opportunities and therefore need better resources and support from the tertiary sector and industry to help out with resource gaps that are not met by governments.

Interviewees had the strong opinion that primary school teachers are instrumental in shaping the image of science that children will take into high school and beyond. However, as few of them have any science degree or even a science background beyond their own school knowledge of science or chemistry, the natural curiosity of children is not utilised and directed sufficiently in most cases to overcome the negative image that they already have formed, namely that chemicals are bad, poisonous and causing pollution.

Consequently a need was expressed for better science education of primary school teachers and for the tertiary sector to develop appropriate materials and experiments, and networking and PD opportunities for primary school teachers. However, it was also important that these types of materials and experiments needed to be able to deliver chemistry understanding in non-privileged schools with low overall resources.

There is a need to review the chemistry curriculum so that those students, who do not aim to enter university at all, will still achieve a high level of chemistry literacy in a learning environment that is not downright scary. There is a need to potentially come to a chemistry syllabus that delivers chemistry at a level that allows basic understanding of principles but does not need to be at the level required for university entry.

The reason for this need was seen in the importance of having a well-educated technical workforce with a technical education background that would support the operations of a more high tech chemical industry and industries such as biotechnology that require more sophisticated and robotic equipment and processes.

The visibility of future chemistry related career paths needs to be increased

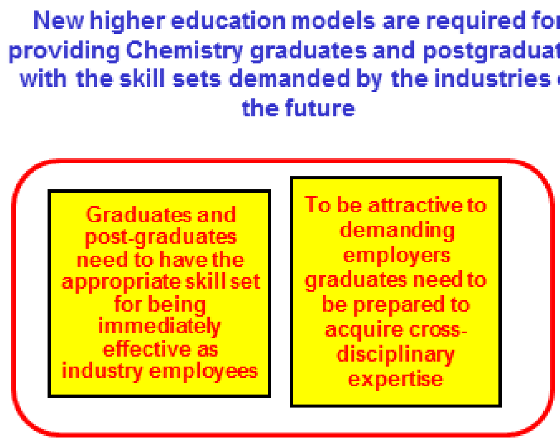
One of the potential reasons for the decline in the participation rate of students in chemistry maybe that there is some confusion about what the qualification might be once students have completed a BSc study path. As studying chemistry does not lead to a qualification of being a “chemist” in a pharmacy there is the perception that studying chemistry must automatically lead to a career in the chemical industry which in a school student’s eyes more often than not has the connotation of developing poisonous chemicals that are “anti-life”.

Of those who select to study chemistry at university, at the beginning of their studies there are three career paths visible to them after achieving a BSc: Further studies as a postgraduate to achieve a better and higher qualification that leads to a position in academia and research, secondly a career in the chemical industry, hopefully in research or at least in analytical chemistry, and thirdly a teaching job in a school.

As there is little perception in the early years of study and even at graduation of what a BSc and major in chemistry might be useful for as a career path, there is a strong need to identify the major research and commercialisation direction and initiatives that will be the foundations of future industries and will be in need of chemistry graduates and researchers.

The overwhelming desire of undergraduates is to find a job in a university or in CSIRO, and hopefully in their town of study. They are initially happy to make sacrifices in terms of low salary but with an entry into the ranks of the early career researcher they are becoming aware of the pressures of competition for a few higher paying positions. The longer they delay an exit into industry the harder they find it later and the more disenchanted they seem to become with the academic career path.

There is a general need to make the two career paths, academia and industry, either mutually exclusive early on or make the requirements and demands more transparent to new undergraduates quite early on in their undergraduate studies.



Currently the undergraduate education of chemistry graduates uses a "cookie cutting" approach and a focus on an academic career and a PhD. There is less focus on and industry career and what an industry entrant might need to be immediately useful in their new position. There may be no need to have a higher degree.

There is a need to interact with industry and develop the requirements that new graduates will need to meet in the future.

Currently industry is satisfied with the technical knowledge of new graduates and new postgraduates but they are also looking increasingly for students with practical experience gained in industry during their undergraduate degree and additional knowledge in adjacent disciplines such as biology or physics or in engineering. The time of the one track blinkered specialist or the average chemistry generalist are definitely over. This applies likewise to newly qualified PhD and Masters Postgraduates.

New product development capability must be improved in the research sector and industry

Currently any Australian industry company can choose any research providers either in Australia or overseas for contracting out specific projects and likewise, any Australian research provider has the choice to collaborate with any Australian or overseas company.

However, this ability to choose becomes constrained by the funds available for R&D in a company and the ability to provide the required research services at the price the company is willing to pay.

There was a clear view in small to medium sized companies that Australia's research providers were "expensive", not willing to take on "mundane" projects and slow to deliver. Larger companies with R&D facilities in other countries only used Australian providers for research problems specific to Australia, for example in the agricultural realm.

Research providers, especially the university based research groups were insufficiently capable of demonstrating the value instead of only the price of their research including the access to research equipment. They were also not sufficiently able to convey why some of the research intensive universities were working at the high end of research and what the benefit of that research could be to industry.

There was a view that the current perceived "anti-science" and "anti-manufacturing" approach of the federal government was leading to a dismantling of industry focused R&D in Australia and thus forcing at least the larger resource based chemical companies that were able to fund larger and more long-term projects, to use international rather than Australian research providers.

Small company interviewees quoted that they were not able to fund the up-front cost of R&D in the current R&D tax environment and that companies who used R&D tax concessions were able to spend it overseas on their preferred research providers instead of on projects with Australian research providers.

Interviewees from larger companies and also from within the research provider community expressed the view that especially the university based research sector needed to embark on more ambitious and higher risk research that would be the basis for future new high end innovation in industry. The time for "run of the mill' research to get ARC funding was seen as past its use by date.

The current way of structuring career paths in universities was seen as detrimental to that type of research.

There was a clear desire by industry and the research sector to improve the ways industry and the research sector collaborate and do business with each other, improve research efficiency and make collaborative projects cheaper.

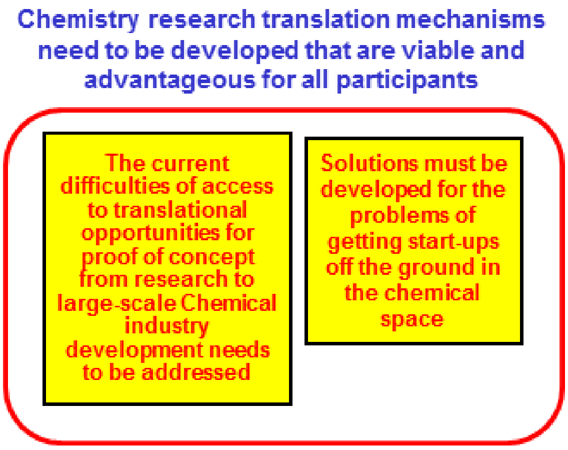
The current inefficient way of applying for research grants with ARC needs to be improved to reduce the substantial overhead of effort in universities and especially of early career researchers, for very little benefit – except prestige, due to the constantly reducing success rate.

The belief of university based researchers that ERA metrics were forcing them to focus on publications and not on industry collaboration or addressing industry problems was seen as limiting them to pursue publishable, and therefore safe, research areas that were providing many publications but were low risk and not leading to innovation, thus wasting money and effort on research that would lead to no results except citations.

Other inefficiencies were seen in the effort required by industry to find a suitable and willing research partner in a university or in CSIRO, especially for small and medium sized industry companies.

A need was expressed for better mechanisms for connecting industry companies with research providers for the benefit of enabling faster development of new technology within a one to five year timeframe from start to market. European examples of innovation mentors with substantial industry R&D experience in large companies rather than academic research experience or government innovation process advisors were cited as good potential examples to follow.

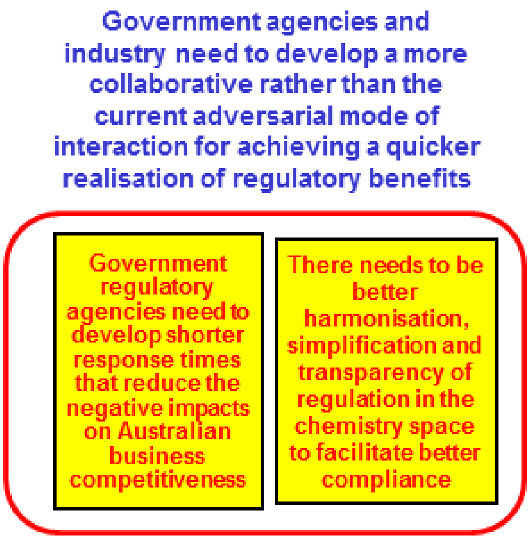
There was a belief amongst industry and research sector interviewees that R&D efficiency could be improved overall if the interaction between industry, CSIRO and universities could be made more efficient. Other countries which succeeded in this had much better technology based outcomes, e.g. Switzerland and Germany.



Once research results have been obtained and the need for proof of concept in an industrial context arises, chemistry research has a hard time to find commercialisation opportunities in Australia, partly because most Australian chemical companies have not the deep pockets to allow them to test new technology in their industrial environment and secondly as funding start-ups in the chemical related field appears to be more difficult than for other areas. Biotechnology related research may be somewhat different and easier.

As for most chemical research translation into industrial process or technology the input of chemical engineering expertise is required there is a need for increased collaboration with the chemical engineering faculties in universities and chemical engineering expertise in other research providers such as CSIRO.

The stakeholder community saw clearly a role for government and the finance industry to make the translation of chemistry research into high end products and processes easier in Australia to prevent technology from leaving Australia and then later finished products being imported back.



Currently interviewees did not see a level playing field in Australia when it came to registration of new products that required registration by the various registration agencies. Some interviewees made accusation that it was easier to get something registered coming from China although a product or chemical then might not be up to standard when it then arrived at the docks in Australia. This applied both to industrial chemicals as well as for example building products.

The current regulatory process was seen as requiring specialist knowledge as it was perceived to lack transparency. A greater need for harmonisation and simplification was thought to be more likely to lead to less red tape, less delays and increased ability of Australian industry to develop products and get them to market before they were obsolete due to overseas companies developing competing products faster.

Interviewees perceived that regulatory agencies could develop a more collaborative and educational approach in their interactions with industry and the research sector. This was expected to better adherence to requirements and better understanding of regulations and processes.

Especially government funded research providers and the education sector were lamenting that the days were over when WHS regulations were more lax or not existent. There is a need to also use a more educational approach to identify the impacts in these two sectors that the WHS regulatory frameworks have on embarking on higher risk research and on keeping science in schools interesting and fun.

Requirements ranking

The ranking scale allowed ranking from “Zero” to “5” for both importance and satisfaction. The midpoint on both scales was 2.5 but this number was not available for selection and so forced respondents to make a choice either on the high or the low side of the importance and satisfaction scales.

In Table 1 below, the means of all satisfaction and importance responses and the calculated opportunity index are provided for each requirement. The requirements are listed in descending order of their opportunity index, consequently the requirement with the highest opportunity index is listed as number 1.

Each of the requirements in the table below has been given a specific stakeholder group and its survey question requirements number of the SurveyMonkey ranking survey.

For example, GOV R2 means that this requirement is a requirement for governments in Australia to address and R2 stands for Requirement 2 in the ranking survey.

Rank #	Requirement / Desired outcome or solution	Mean importance (0-5)	Mean satisfaction (0-5)	Opportunity index (1-10)
1	**GOV R2**: Australia needs to adopt world's best practice in Science policy making at all government levels.	4.9	1.5	8.3
2	**GOV R8**: Australia needs more science-literate leaders, policy makers and advisors in Government, who can better understand technology driven change in industry and society	4.7	1.3	8.1
3	**GOV R24**: The allocation of research funds to research institutions needs to be simplified to reduce the currently substantial time overhead for grant application writing	4.5	1.2	7.7
4	**GOV R3**: Australia needs to be pro-active in adopting successful models of innovation policies, strategies and schemes from countries that are leading the innovation rankings	4.7	1.8	7.5
5	**EDU R13**: The gaps in science literacy of primary school teachers needs to be addressed as a matter of urgency to prevent students' curiosity and interest in science from declining prior to entry in high school	4.5	1.7	7.3
6	**ALL R9**: The science literacy of the Australian general public needs to be upgraded to facilitate informed and better public debate on global issues that require the input of chemistry science for effective solutions	4.5	1.7	7.2
7	**ALL R7**: The chemistry community collectively needs to take on the responsibility for the way chemistry is portrayed to the general public and in the media and to work on ways to improve the public perception of chemistry	4.5	2.0	7.0
8	**IND R1**: Australia needs to adopt world's best practice in industry processes in the chemical industry and industry sectors that require substantial chemistry knowledge	4.7	2.6	6.9
9	**ALL R6**: All segments of the Australian chemistry community need to develop a unified collaborative approach for overcoming the causes and impacts of chemistry illiteracy and poor image	4.4	2.0	6.7
10	**GOV R37**: Government-funded agencies need to develop shorter response times in their interaction with industry companies so that negative impacts on business competitiveness are reduced	4.3	1.9	6.7
11	**GOV R4**: Australia must implement existing highly effective, innovation schemes and mechanisms from leading innovating countries if they can be implemented at low cost or cost-neutral in Australia	4.3	1.9	6.6

12	**GOV/IND/RES R33**: Chemistry research translation mechanisms (from research to commercial development) need to be developed that are viable and advantageous for all participants in an environment of limited industry profitability and limited government support	4.2	1.9	6.5
13	**GOV/IND/RES R34**: The current difficulties of access to translational opportunities for proof of concept from research to large-scale Chemical industry development needs to be addressed	4.2	1.9	6.5
14	**GOV/IND/RES R35**: Solutions must be developed for the problems of getting a higher number of start-ups off the ground in the chemical space	4.1	1.8	6.4
15	**EDU R14**: Engaging chemistry teaching materials need to be developed that are easily accessible by schools and teachers in all schools including remote, rural and economically disadvantaged schools	4.3	2.2	6.4
16	**IND/RES R25**: New, effective and affordable models for R&D collaboration between chemical industry companies and research providers need to be developed to enable collaboration in a cash-poor operating environment	4.1	1.9	6.4
17	**HER/EDU R10**: chemistry education models and engaging materials need to be developed that help teachers to deliver improved educational and chemistry literacy benefits to children of all ages and backgrounds (i.e. from pre-school to year 12)	4.4	2.5	6.3
18	**RES/GOV R26**: The capabilities of Australian research providers must be strengthened substantially to enable them to become the preferred R&D partners for both Australian and international companies who seek high-end innovation	4.3	2.4	6.2
19	**EDU/HER R16**: As a matter of urgency professional development mechanisms must be developed for chemistry (science) teachers in regional and remote locations	4.0	1.9	6.2
20	**EDU R11**: Age-specific and engaging teaching and learning models need to be implemented that do not exclude disadvantaged children but instead lift their participation in science and chemistry and their educational outcomes	4.2	2.3	6.2
21	**RES R30**: More balanced reward and promotion mechanisms in research organisations must be developed that do not disadvantage commercial activity and creation of patentable IP	4.1	2.1	6.2
22	**IND/RES/GOV R39**: There need to be better, more flexible models for cost recovery that facilitate the development of new chemical products to balance the upfront costs of R&D investment in new product development	4.1	2.0	6.2
23	**GOV R36**: Government agencies need to develop a more education focused and collaborative rather than an adversarial mode of interaction with Australian industry companies	4.1	2.2	6.1

24	**RES/IND R5**: Research data from Australian research providers (e.g. universities, CSIRO) need to be analysed regularly in a systematic manner to identify potential technologies that could be translated into new products and processes with appropriate support	4.0	2.0	6.1
25	**HER/IND R17**: Engaging information material needs to be developed for parents and middle school students that provide information on the types of employment pathways that a solid chemistry education in high school would facilitate in the future	4.1	2.2	6.1
26	**RES R23**: To improve research efficiency and effectiveness, the Australian research sector has to develop increased skills, strategies and better mechanisms that are not solely reactive to the government policies of the day	4.1	2.2	6.0
27	**HER/EDU/IND R18**: Up to date and better information must be made available to high school teachers and higher education providers about chemistry related future job market developments to enable adaptation of teaching to future needs	4.0	2.2	5.9
28	**RES R27**: Australian research providers need to actively and routinely provide information about their research capabilities, research equipment, and research services to Chemical companies and companies in other industry sectors to facilitate appropriate R&D partner selection by industry	4.0	2.1	5.8
29	**HER R31**: Higher education providers must develop distinct programs that cater for different career pathways (academic; industry and teaching) to prevent overcrowding of the academic pathway with consequent poor career prospects and inadequately equipped graduates for industry and teaching	3.9	2.1	5.8
30	**GOV/EDU R15**: The chemistry knowledge requirements for achieving the basic skills needed by the technically oriented workforce of the future need to be determined to ensure school leavers of the next decade and beyond are equipped with the necessary chemistry knowledge regardless of their background situation or location	4.0	2.2	5.8
31	**GOV R38**: There needs to be better harmonisation, simplification and transparency of regulation in the chemistry space to facilitate better compliance and quicker realisation of benefits from commercialisation of new chemistry based research	4.1	2.4	5.8
32	**RES/GOV R29**: New metrics for chemistry research efficiency and effectiveness need to be developed that provide a more balanced picture of a research provider's level of excellence in the international context than just publication focused metrics	4.0	2.2	5.8
33	**HER R32**: New higher education models are required for providing chemistry graduates and postgraduates with the skill sets demanded by the industries of the future	4.0	2.5	5.5

34	**RES R28**: Australian research institutions need to abandon their focus on safe, run-of-the-mill chemistry research areas in favour of more high risk, strategic work that can become the source of future innovation	3.8	2.4	5.1
35	**HER R20**: Chemistry graduates (esp. MSc and PhD) need to have more transferable skills, to enable flexibility. These include generic maths skills and problem solving skills	4.0	3.0	5.1
36	**HER R22**: Graduates and post-graduates need to include more practical industry experience during their studies to enable them to be more effective as industry employees	3.6	2.2	5.1
37	**HER R21**: Universities need to develop a more flexible approach to teaching chemistry to enable fast adaptation to the needs of new and more cross-disciplinary professional pathways	3.7	2.6	4.8
38	**HER/IND R19**: To be attractive to the demanding employers of the future in all sectors graduates need to have cross-disciplinary expertise, such as in biology, engineering, toxicology, physics, or earth science etc.	3.6	2.5	4.7
39	**GOV/RES R12**: The reasons for and the benefits of adhering to Work Health & Safety regulations need to be better communicated throughout the chemistry community and especially the research sector	3.9	3.2	4.7

Table 1: Requirements ranked according to opportunity index.

The following abbreviations mean that the development of solutions for the requirement lies in the realm of these value chain sectors.

GOV = Government
IND = Industry
EDU = School education
HER = Higher education and research
RES = Research organisations
ALL = All stakeholders

All requirements were ranked higher than 3.5 on the importance scale and only six were ranked above 2.5 on the satisfaction scale.

This means that the chemistry stakeholder segments have a large number of poorly met requirements for solutions to important issues and problems that currently prevent high performance and limit international competitiveness.

Kano analysis

Based on experience with similar projects, requirements with an opportunity index of higher than 5 are worth pursuing in terms of developing solutions. The reason for this becomes clear when the requirements are plotted in a Kano diagram. In the Kano diagram below the red numbers show the top 13 requirements based on the opportunity index ranking, the yellow numbers show the bottom 13 requirements (Figure 2).

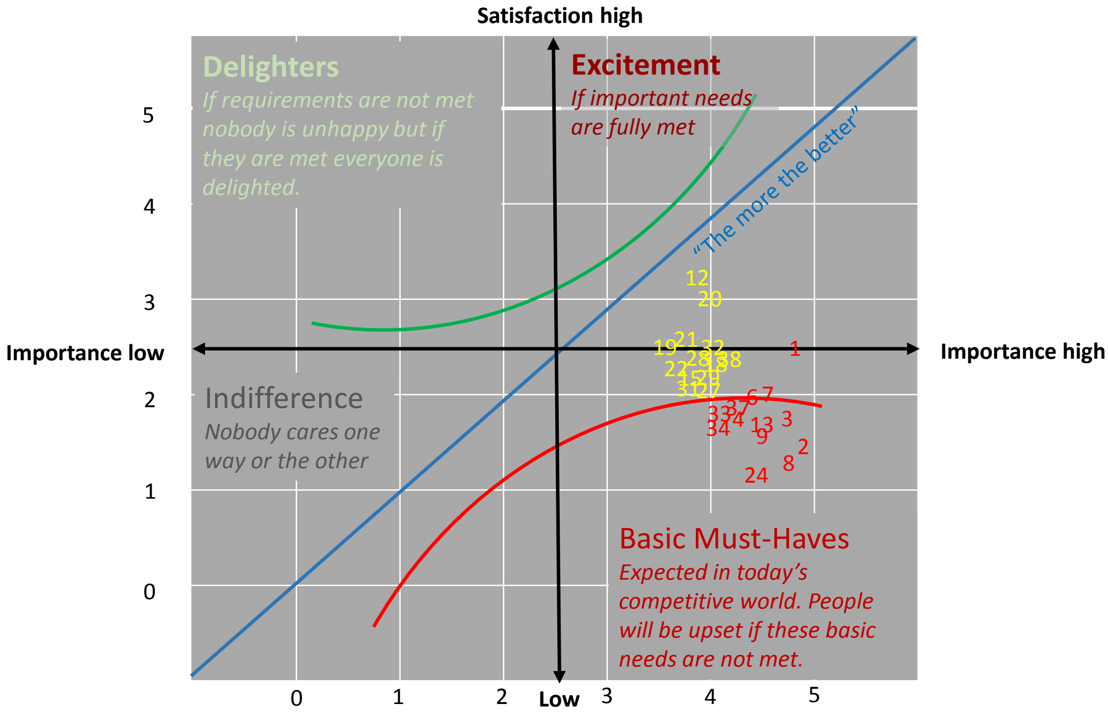


Figure 2: Kano Diagram of requirements based on their importance and satisfaction mean scores.
Please note: **Red** numbers are the Requirements numbers of the top 13 requirements based on their opportunity index, **yellow** numbers are the bottom 13 requirements based on their opportunity index. The remaining 13 requirements are not depicted in this diagram.

This diagram shows that the top 13 requirements based on their opportunity index ranking are all in the basic "Must-have" category and all but two of the bottom requirements are still under the "linear performance" line of "The more the better". The remaining requirements in the middle of the opportunity index range are not shown in the diagram as they are also located in the right half of the diagram and overlapping the bottom yellow and the top red numbers.

Those requirements that ranked in the top third, based on their opportunity index ranking, are shown in red font. Those that ranked in the bottom third are shown in yellow. Requirements in the middle third are not shown

There was no additional clarity about which of the middle and bottom third requirements would need to be addressed in the future.

To gain additional clarity about which of the middle and bottom third requirements would need to be addressed in the future, additional scoring and ranking was performed on:

1. Urgency to implement effective solutions for each requirement (Score 1 very low urgency, 2 = low, 3 = moderately urgent, 4 high urgency and 5 = extremely urgent)
2. Ease of implementation of solutions for each requirement (Score 1 extremely difficult to implement, 2 = difficult to implement, 3 = moderately easy, 4 easy to implement, and 5 = very easy to implement).

Plotting the top third, middle third and bottom third of the requirements (based on their opportunity index) into a new Kano diagram in which the vertical axis was the mean implementation index and the horizontal axis the mean urgency index of each requirement, resulted in a wider spread of the requirements in the diagram (Figure 3).

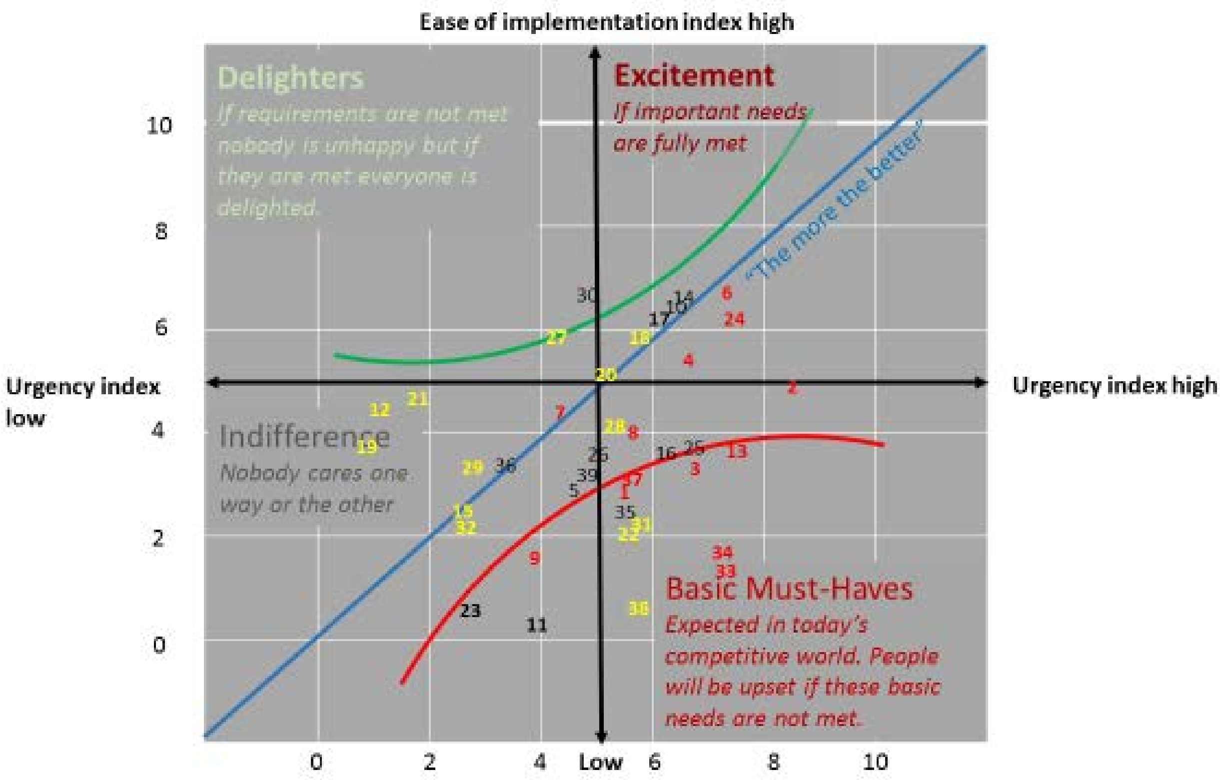


Figure 3: Kano diagram showing a wider scattering of the requirements but that most "must have" requirements are still must have requirements despite their issues with low or moderate implementability.

An overall "Attractiveness index" was then calculated, based on the opportunity index, mean implementability and mean urgency of each requirement, hoping to find a best fit rank for each requirement that would ensure that all of the most important, urgent and currently poorly met requirements could be easily implemented, and spending of effort and resources on hard to implement or less important requirements could be avoided or delayed.

The requirements ranking in the top third on the "Attractiveness index" scale are listed in Table 2 and in Figure 4, with both the opportunity index and the attractiveness index shown for each of these requirements.

Rank	Requirement	Opportunity index	Attractiveness index
1	**ALL R6:** All segments of the Australian chemistry community need to develop a unified collaborative approach for overcoming the causes and impacts of chemistry illiteracy and poor image	6.7	6.7
2	**EDU R14:** Engaging chemistry teaching materials need to be developed that are easily accessible to schools and teachers in all schools including remote, rural and economically disadvantaged schools	6.4	6.4
3	**HER/EDU R10:** Chemistry education models and engaging materials need to be developed that help teachers to deliver improved educational and chemistry literacy benefits to children of all ages and backgrounds (i.e. from pre-school to year 12)	6.3	6.3

4	**GOV R24:** The allocation of research funds to research institutions needs to be simplified to reduce the currently substantial time overhead for grant application writing	7.7	6.2
5	**HER/IND R17:** Engaging information material needs to be developed for parents and middle school students that provide information on the types of employment pathways that a solid chemistry education in high school would facilitate in the future	6.1	6.1
6	**HER/EDU/IND R18:** Up to date and better information must be made available to High School teachers and higher education providers about Chemistry related future job market developments to enable adaptation of teaching to future needs	5.9	5.9
7	**GOV R4:** Australia must implement existing highly effective, innovation schemes and mechanisms from leading innovating countries if they can be implemented at low cost or cost-neutral in Australia	6.6	5.3
8	**HER R20:** Chemistry graduates (esp. MSc and PhD) need to have more transferable skills, to enable flexibility. These include generic maths skills and problem-solving skills	5.1	5.1
9	**GOV R2:** Australia needs to adopt world's best practice in Science policy making at all government levels.	8.3	5.0
10	**RES R30:** More balanced reward and promotion mechanisms in research organisations must be developed that do not disadvantage commercial activity and creation of patentable IP	6.2	5.0
11	**RES R28:** Australian research institutions need to abandon their focus on safe, run-of-the-mill chemistry research areas in favour of more high risk, strategic work that can become the source of future innovation	5.1	4.1
12	**RES R27:** Australian research providers need to actively and routinely provide information about their research capabilities, research equipment, and research services to Chemical companies and companies in other industry sectors to facilitate appropriate R&D partner selection by industry	5.8	4.1
=13	**EDU R13:** The gaps in science literacy of primary school teachers needs to be addressed as a matter of urgency to prevent students' curiosity and interest in science from declining prior to entry in High School	7.3	3.8
=13	**IND/RES R25:** New, effective and affordable models for R&D collaboration between chemical industry companies and research providers need to be developed to enable collaboration in a cash-poor operating environment	6.4	3.8

Table 2: Top third of requirements ranked on their Attractiveness index.

As the attractiveness index favours those requirements that have high opportunity scores, high implementability scores and high to moderate urgency for finding effective solutions, using the attractiveness index alone would automatically ignore all of those requirements that are must haves that are hard to implement even though they also might be urgent.

This indicates that the attractiveness index is a good index for finding the requirements that will provide quick wins if the attractive requirements are implemented and for eliminating those requirements to which the stakeholder community feels ambivalent. However, the attractiveness index does not rank those requirements highly that are or could be vital "must haves" for the long term survival and strategic positioning of chemistry in the future—but which are hard to implement.

Therefore investment into developing solutions just for the easy to implement and currently urgent requirements may not be sufficient.

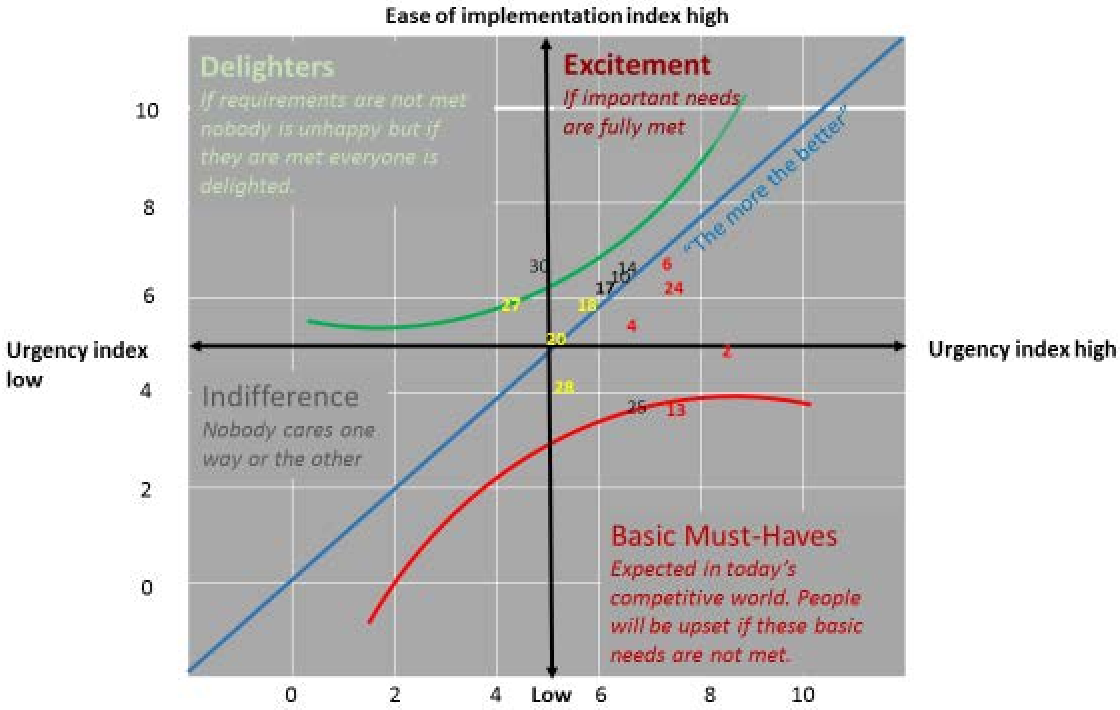


Figure 4: Top third of the requirements ranked on attractiveness of implementation

Based on the three Kano diagrams and the full list of requirements ranked on opportunity index (importance and satisfaction) alone and on the attractiveness index (importance, satisfaction, urgency and implementability) a priority list of requirements can be created.

However, given that the decadal plan is covering a decade and the implementation plan for the decadal plan recommendations will also cover a decade, solutions to the requirements will not need to be implemented all at once or concurrently and for each of the harder to implement requirements appropriate solutions and implementation plans need to be developed to avoid future dissatisfaction and frustration of stakeholders.

Must have requirements

Must haves that rank high on opportunity index and on attractiveness index

All bar two of the opportunity index "must haves" (red font) in Figure 2 are also urgent in their need to find solutions that address the lack of satisfaction with the current state of implementation.

However, only five of them rank in the top third on the attractiveness index also (Table 3) because their implemetability was estimated as high. If these requirements are met by providing viable and effective solutions, the satisfaction of the stakeholder community is expected to be high. These requirements need to be implemented as a matter of priority.

Requirement	Opportunity Index	Attractiveness Index
ALL R6: All segments of the Australian chemistry community need to develop a unified collaborative approach for overcoming the causes and impacts of chemistry illiteracy and poor image	6.7	6.7
GOV R24: The allocation of research funds to research institutions needs to be simplified to reduce the currently substantial time overhead for grant application writing	7.7	6.2
GOV R4: Australia must implement existing highly effective, innovation schemes and mechanisms from leading innovating countries if they can be implemented at low cost or cost-neutral in Australia	6.6	5.3
GOV R2: Australia needs to adopt world's best practice in Science policy making at all government levels.	8.3	5.0
EDU R13: The gaps in science literacy of primary school teachers needs to be addressed as a matter of urgency to prevent students' curiosity and interest in science from declining prior to entry in High School	7.3	3.8

Table 3: Must have requirements that rank high both on opportunity index and on attractiveness index

Must haves that are both urgent and easy to moderately easy to implement

Three of these requirements are thought to be easy to implement through appropriate steps taken by government. The first requirement in Table 4 requires collaboration and motivation to act of the combined stakeholder community to address chemistry illiteracy and its impact, but it is believed to be relatively easy to achieve as this would be of interest to all stakeholders.

Requirement	Opportunity Index	Attractiveness Index
ALL R6: All segments of the Australian chemistry community need to develop a unified collaborative approach for overcoming the causes and impacts of chemistry illiteracy and poor image	6.7	6.7
GOV R24: The allocation of research funds to research institutions needs to be simplified to reduce the currently substantial time overhead for grant application writing	7.7	6.2
GOV R4: Australia must implement existing highly effective, innovation schemes and mechanisms from leading innovating countries if they can be implemented at low cost or cost-neutral in Australia	6.6	5.3
GOV R2: Australia needs to adopt world's best practice in Science policy making at all government levels.	8.3	5.0

Table 4: Must have requirements that are easy to implement and very urgent to address

The top three requirements are located in the top right quadrant of the Kano diagram in Figure 2 and closer to the linear performance line that indicates that "the more the better" or the more effective, simpler or collaborative the approach is the more exited the stakeholder community will be about the implemented solutions.

Must haves that are urgent and hard to implement

Table 5 shows the requirements that are urgent to address but hard to implement. They are believed to be fundamental to ensuring that new research outcomes from the research sector are reaching the market. This requires collaboration between the research sector, industry and government, but they also need careful consideration in the decadal plan implementation plan.

However, the benefit of investing into these two hard to implement requirements are believed to be high both for the relevant stakeholder segments but also for the country as a whole.

Requirement	Opportunity Index	Attractiveness Index
GOV/IND/RES R33: Chemistry research translation mechanisms (from research to commercial development) need to be developed that are viable and advantageous for all participants in an environment of limited industry profitability and limited government support	6.5	1.3
GOV/IND/RES R34: The current difficulties of access to translational opportunities for proof of concept from research to large-scale Chemical industry development needs to be addressed	6.5	1.3

Table 5: Must have requirements that are urgent and difficult to implement

Must haves that moderately urgent but moderately difficult or difficult to implement

Four of the five requirements in Table 6 are all about the need to achieve world's best practice. There is a clear need for government to address three of these requirements relating to policy making, innovation process and strategy and best practice in services to their stakeholder community and their customers.

The last requirement in the table addresses the need for the stakeholder community as a whole to take on the responsibility for actions to address the poor image of chemistry and be proactive in dealing with the non-scientific general community.

Requirement	Opportunity Index	Attractiveness Index
GOV R8: Australia needs more science –literate leaders, policy makers and advisors in Government, who can better understand technology-driven change in industry and society	8.1	2.7
GOV R3: Australia needs to be pro-active in adopting successful models of innovation policies, strategies and schemes from countries that are leading the innovation rankings	7.5	3.1
IND R1: Australia needs to adopt world's best practice in industry processes in the chemical industry and industry sectors that require substantial chemistry knowledge	6.9	2.2
GOV R37: Government funded agencies need to develop shorter response times in their interaction with industry companies so that negative impacts on business competitiveness are reduced	6.7	2.2
ALL R7: The chemistry community collectively needs to take on the responsibility for the way chemistry is portrayed to the general public and in the media and to work on ways to improve the public perception of chemistry	7.0	2.5

Table 6: Must have requirements that are moderately urgent and moderately difficult to implement

Must have requirements that are not very urgent and very difficult to implement

The only must-have requirement in Table 7 that was estimated to be very important with current low satisfaction about being met was seen as extremely hard to implement. Due to its moderate urgency it is likely that other requirements, if met, will over time result in an automatic slow increase in satisfaction with this requirement being met.

Although this is a must have requirement according to its high opportunity index, it lies in the bottom left hand quadrant of the Kano diagram in Figure 3 which means that stakeholders are somewhat ambivalent about its implementability and urgency.

Requirement	Opportunity index	Attractiveness index
ALL R9: The science literacy of the Australian general public needs to be upgraded to facilitate informed and better public debate on global issues that require the input of chemistry science for effective solutions	7.2	0.6

Table 7: Must have requirements that are not very urgent and very difficult to implement.

Exciter requirements

Exciter requirements are generally requirements relating to performance, i.e. the higher the performance, the easier the process, the better.

Requirement	Opportunity index	Attractiveness index
EDU R14: Engaging chemistry teaching materials need to be developed that are easily accessible to schools and teachers in all schools including remote, rural and economically disadvantaged schools	6.4	6.4
HER/EDU R10: Chemistry education models and engaging materials need to be developed that help teachers to deliver improved educational and chemistry literacy benefits to children of all ages and backgrounds (i.e. from pre-school to year 12)	6.3	6.3
HER/IND R17: Engaging information material needs to be developed for parents and middle school students that provide information on the types of employment pathways that a solid chemistry education in high school would facilitate in the future	6.1	6.1
HER/EDU/IND R18: Up to date and better information must be made available to High School teachers and higher education providers about chemistry related future job market developments to enable adaptation of teaching to future needs	5.9	5.9
HER R20: Chemistry graduates (esp. MSc and PhD) need to have more transferable skills, to enable flexibility. These include generic maths skills and problem-solving skills	5.1	5.1
RES R28: Australian research institutions need to abandon their focus on safe, run-of-the-mill chemistry research areas in favour of more high risk, strategic work that can become the source of future innovation	5.1	4.1

Table 8: Exciter requirements that are high on opportunity rank and attractiveness rank and are urgent and easy to implement

Table 8 shows a list of requirement of this kind. Even though these requirements are not strict “must have” requirements, addressing these requirements is expected to create excitement and lead to benefits to the education sector with substantial flow-on benefits to the whole chemistry stakeholder community.

However, addressing just the exciter requirememts without addressing the must-have requireemnts will lead to increased dissatisfaction if better educated chemistry literate school leavers and graduates cannot find relevant work in a flourishing industry or research sector. This can be compared to driving an exciting car with top performance in speed and fuel consumption that has not got the must have such as functioning brakes or airbags.

Delighter requirements

There are two delighter requirements in the Kano diagram in Figures 3 and 4. They are easy enough to implement, but not extremely urgent but if implemented stakeholders would be delighted (Table 9). Both are clearly requirements for the research sector to address. If met, these requirements will have a high impact on the ability to retain high performing researchers that are taking risks in innovation and enable industry to find appropriate R&D partners, services, or infrastructure for research and new technology development.

Requirement	Opportunity index	Attractiveness index
RES R30: More balanced reward and promotion mechanisms in research organisations must be developed that do not disadvantage commercial activity and creation of patentable IP	6.2	5.0
RES R27: Australian research providers need to actively and routinely provide information about their research capabilities, research equipment, and research services to Chemical companies and companies in other industry sectors to facilitate appropriate R&D partner selection by industry	5.8	4.1

Table 9: Delighter requirements that lead to high satisfaction if met

The other requirements

Requirements not listed in the above tables but shown in the Kano diagram in Figure 3 as black or yellow requirement numbers are in the middle or lowest third of the requirements based on their opportunity index ranks. They are either not extremely important or they are already partly met.

If they are located within either the top right or the bottom right quadrant in the Kano diagram in Figure 2 they are moderately urgent, moderately easy or somewhat difficult to implement but because they are ranking in the middle or bottom third on opportunity index they are already partly met or not of the highest importance in the view of the stakeholder community.

If these requirements are located in the lower left quadrant of the Kano diagram in Figure 3 they are not urgent to address and they are all somewhat difficult to implement.

This does not mean these requirements should be ignored altogether but they should be analysed further, considering that none of the 39 requirements received an importance rank below 2.5.

Stakeholder segment requirements—Who owns the requirement?

Throughout the interview process, requirements definition and the requirements ranking process individuals focused to a large degree on the specifics of their situation and the current operating environment of their sector but took a more ‘helicopter view” when focusing on the long term requirements for the next decade.

Clearly many of the requirements can only be addressed by collaboration between stakeholder segments to achieve tangible outcomes. Several others are at such high level that their implementation requires additional work on what specific features any potential solution needs to include, which requires then further work on specific requirements related to a specific concept to enable cost estimation prior to implementation.

Government

The four top ranking requirements in Table 1 were clearly seen as the responsibility of government.

Eight of the top 13 (the top third) of the requirements where seen to be the responsibility of the government stakeholder segment or required at least strong input by this segment.

Generally the requirements related to the perception that government did not apply international best practice process in policy making in general and in innovation policy making in particular, thus negatively affecting other stakeholder segments. The survey respondents voiced the need for government to explore and analyse international models of best practice in innovation policy and strategy of countries that lead OECD innovation and competitiveness rankings and have to depend on technology innovation in an environment of their own strong currency.

A need for increasing innovation efficiency by scrapping much of the competitive funding process overhead was seen as very important, as well as improving research translation processes for chemistry related research substantially to avoid research funds being spent and results sitting on the shelf without being commercialised because proof of concept in a manufacturing environment is not funded.

There is a clear perception that the Australian government at its highest levels has low science literacy and does not understand the positive correlation between investment in science and high end technology outcomes that then lead to increased competitiveness of many Australian industries internationally.

Education in schools

The top requirements in Table 1 relating to international best practice directed at governments generally apply to the education sector as well as this stakeholder segment is clearly government funded.

The top requirement specifically addressed to the government education sector is the requirement for improving the science literacy of primary school teachers as they are in a key role of influence over the motivation of primary school children to either accept chemistry and science as interesting and worthwhile for investing time into or to devalue it from the start.

Survey respondents felt strongly that more engaging teaching models and materials should be made available to teachers in an environment of more restrictive WHS regulations in order to enable teaching of chemistry and engagement and participation of school students in all school types.

There was a clear view that equality of access was important to enable schools with a population of disadvantaged students to participate and excel in chemistry and also that access to professional development was easier to access by teachers in all geographic areas.

Higher education

Requirements that will need to be addressed by the higher education stakeholder segment were ranked in the middle and lower thirds of the requirements ranking table (Table 1) but high on the 'Exciter' ranking table.

They can be grouped into three broad different topics:

- Chemistry teacher education and professional development support,
- Education of graduates and postgraduates for their future roles,
- Transparency of education pathways for graduates.

The requirements for providing better transparency about the realities and limitations of a career in chemistry research in academia or a government research laboratory and the features and benefits of careers in chemistry teaching and in industry were voiced strongly during the interviews but these requirements were ranked lower than many others, mainly due to the perceived higher importance than those addressed to the government and education stakeholder segments. However, the satisfaction scores with the current situation were still below the midpoint of the ranking scale.

A preference of graduates for employment in research is currently evident and therefore a focus of chemistry departments is not providing a specific stream for undergraduates who want to pursue a career in teaching. There was clear dissatisfaction with the current situation but as the current higher education model still provides teachers that are going to find a job, this requirement ranked only in the bottom quarter of the ranking table because it was seen only to be "important" but not "extremely important".

The requirements relating to "job readiness" in the future and education of job ready graduates the ranking results of the survey respondents clearly show that many respondents did not see a need for more cross-disciplinary skills in the future. This is in contrast to what many industry interviewees and chemists with broad international experience and with a view across several industries were seeing as important. This specific ranking result indicates that the majority of respondents were not aware of emerging global trends in research and industry.

Similarly the interest of industry in engaging with undergraduate and postgraduate students via industry placements were ranked in the bottom third of the requirements. Approximately 7% of respondents were happy with the current level of industry engagement, the other 93% felt either very dissatisfied or neutral. It appears that there is some ambivalence about this requirement but there is a clear opportunity for using industry placements of students for both improvements of student educational outcomes as well as improved industry/higher education sector engagement an relationships.

Research

Requirements of the research stakeholder segment were ranked in the middle and lower thirds of the ranking table.

They can broadly be grouped into the following topics:

- Requirements related to more effective mechanisms of translation of research results into new chemistry based products or processes,

- Requirements related to more effective collaboration with industry, other research providers and across disciplines,
- Research capabilities to become more competitive globally to industry investors and collaborators,
- Improved metrics for research efficiency and effectiveness and career promotion,

The importance scores for the research stakeholder requirements show that the chemistry research providers clearly are aware of the importance of getting their research results translated into commercial outcomes, but that they are not satisfied with the current process of research translation that is available to them.

The interview process uncovered that both the research stakeholder segment as well as industry interviewees found that the current process of collaboration and interaction left a lot to be desired. Although some enterprises have over time established good working relationships with research organisations they have indicated that the journey to a trusted relationship has been long and started with low-risk interactions.

The main reason for reluctance to engage with the research sector was the costs involved with the research in those institutions and the timeframes to delivery of results. Therefore the requirement to deal with the up-front cost of high-risk research was seen as important and currently not sufficiently addressed.

The issue of competitiveness of research providers for industry is also reflected in the requirement that relates to the capabilities of research institutions to become more internationally competitive and acceptable as research collaborators to industry.

The high focus on competitive grant processes in Australia is driving competition between research providers and is hindering collaboration and therefore is a drain on research efficiency and effectiveness. Therefore the requirement for streamlining of research funding allocations more efficient was ranked third highest overall.

Several of the requirements that predominantly relate to chemistry research and the research process are not solely the responsibility of the research sector. Solutions can only be found if industry and government collaborate to determine what each of these stakeholder segments needs out of better collaboration and investment in chemistry research. This then could lead to improved impact of chemistry research over time.

All stakeholders—in collaboration

Three requirements stand out that are requirements of and to all stakeholders of the chemistry community. All three rank in the top ten requirements and all relate to the image of chemistry in the eyes of the general public, the lack of sufficient science literacy of the general public and the need to address the issue.

However, the future response to this issue is thought to be the responsibility of all stakeholders and needs to be addressed in a collaborative and fully aligned manner.

Conclusions and next steps

The ranking of the requirements reflected the need for remediation of the suboptimal linkages between stakeholder segments of the chemistry community and for strategies and processes for improving the coordination and alignment between the segments for an ultimately increased impact of Australian chemistry in the long term.

The opportunity index is one way of ranking the requirements. The ranking is aligned with the issues identified in the operating environment map as well as the stakeholder needs map.

However, analysis reveals that neither the chemistry community as a whole nor any of its stakeholder segments have the capabilities or resources to address all of them.

The dilemma is that all requirements will need to be met over time for Australian chemistry to become one of the top global players instead of playing the game 'who is the tallest midget' but the resources and capabilities for achieving this are currently limited.

The next steps will need to be, to define also how vital and how urgent each requirement is for achieving the overall vision for chemistry.

Vital requirements should be those that need to be met to ensure the vitality and the survival of chemistry as a "business" in Australia. Urgent requirements are those that ensure that chemistry can have enough resources to live to tomorrow. After having decided which of the urgent and the vital ones should be addressed the question of how implementable each of them is needs to be addressed, such as considering cost, people available, capabilities of the various stakeholder segments and the availability and appropriateness of metrics to measure progress.

The process for arriving at a number of implementable requirements and costed options for solutions will include the construction of a number of Kano plotting graphs and Pareto diagrams.

In the end decisions will need to be made on a limited number of implementable requirements that will need to be resourced and their progress measured against international benchmarks. This then will also require a good and well-structured benchmarking process.

Attachment 1: Interview Guide - Industry

1. **(warm-up question) Describe briefly what you do and how your company fits into the chemical industry value chain globally and locally?**
   - What are your inputs and outputs?
   - Trends that are going to affect you in the next 10 years?
   - Threats? Weaknesses
   - Opportunities, Strengths

2. **Given what is put out by ICCA, World Economic Forum, G2A2 etc in terms of analysis, roadmaps and strategic plans how much notice is your company and the Australian Chemical industry taking of this for their own roadmaps and innovation efforts?**

Innovation record in your part of the chemical industry – requirements

- Switzerland – No 1 global performer on competiveness index, what are we not doing that they are doing right?
- Your opinion – what is important and why for innovation in your segment?

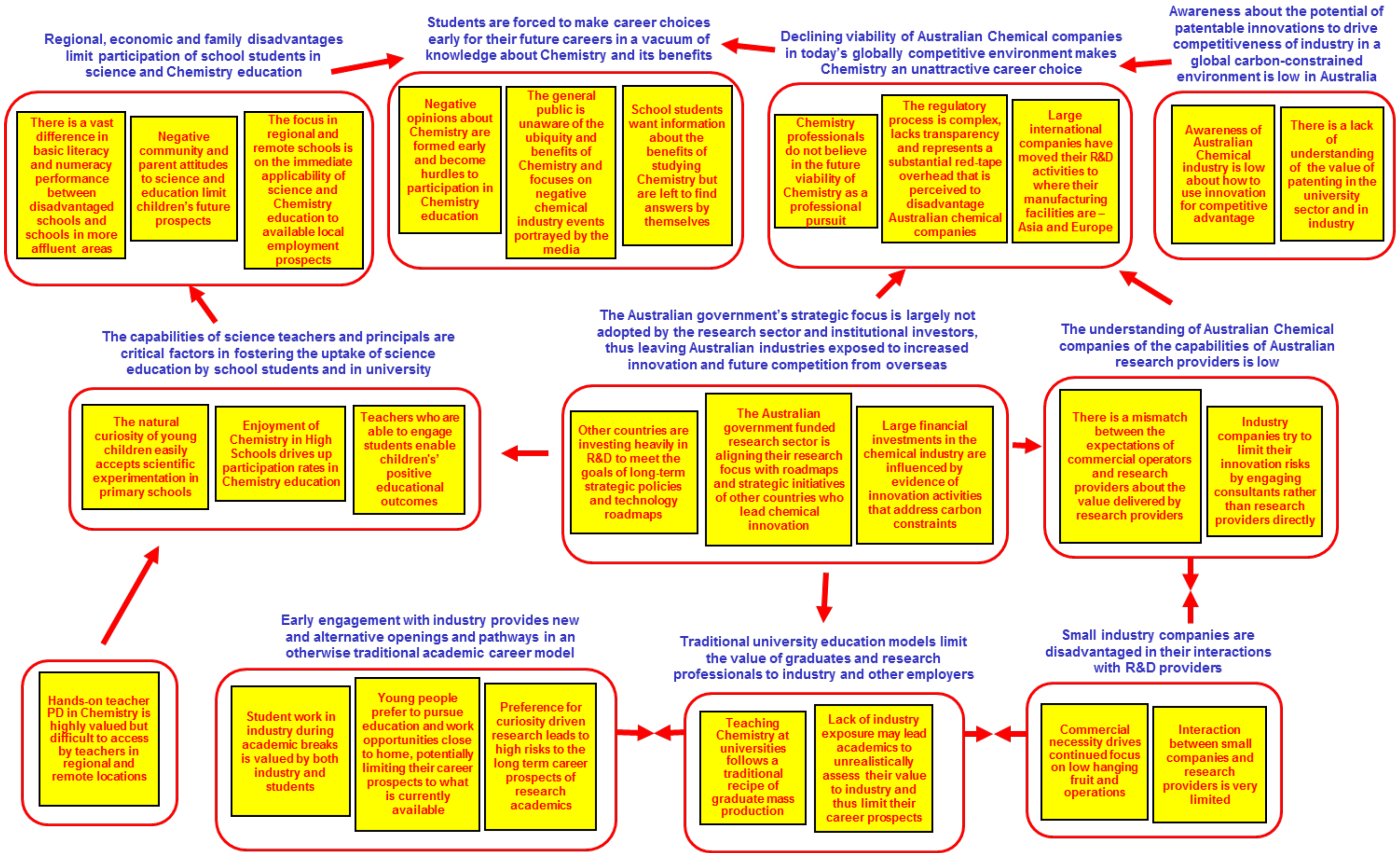
3. **What was your worst experience in the last year or two re the “chemical industry system” or some part of the chemistry community letting you down in your role - in terms of information, collaboration, commercial interaction, supply of goods and services, support, etc.?**
   - How did you recover?
   - What could have been done differently at the time?

4. **If I had a magic wand to wave over the chemical industry here in Australia and you could change anything you wanted to make life easier for you and your company (or the next generation of industry chemists), what would you change?**
   - Infrastructure, education, resources, policies, services available to you etc.?
   - How would you change industry’s interaction with the chemistry community?
   - What would you steal and transport here from elsewhere?
   - What would you eliminate?

Attachment 2: Chemistry stakeholder operating environment map

How effective is the "Chemistry Community" in contributing to the overall performance and competitiveness of the sector and Australia?

Alignment of the segments of the "Chemistry Community" is suboptimal for a reaching a common vision and existing linkages are weak and rusty.



Attachment 3: Chemistry community stakeholder needs map

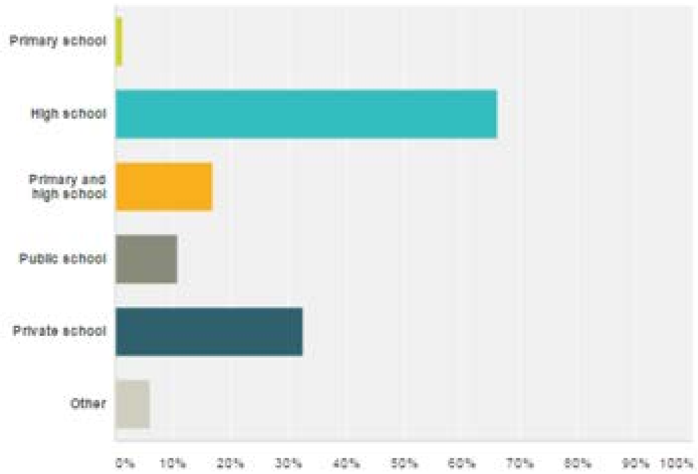
Appendix 14 – Chemistry teacher survey

20-Question Survey July to November 2014

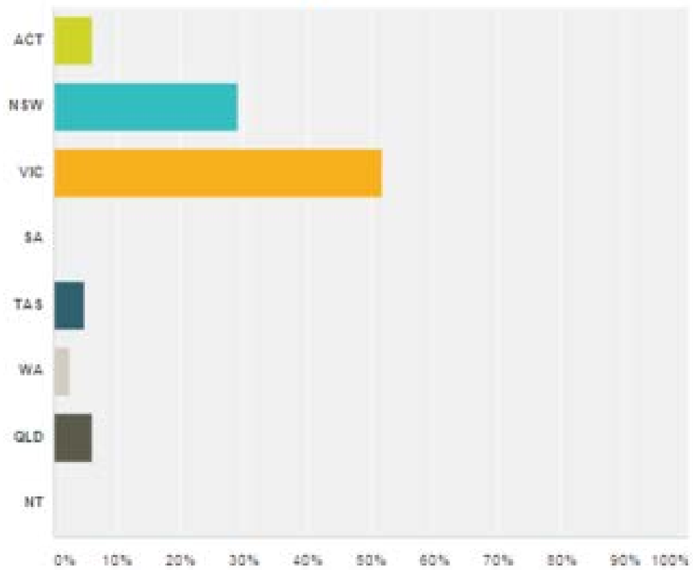
83 Respondents

66% male -34% female

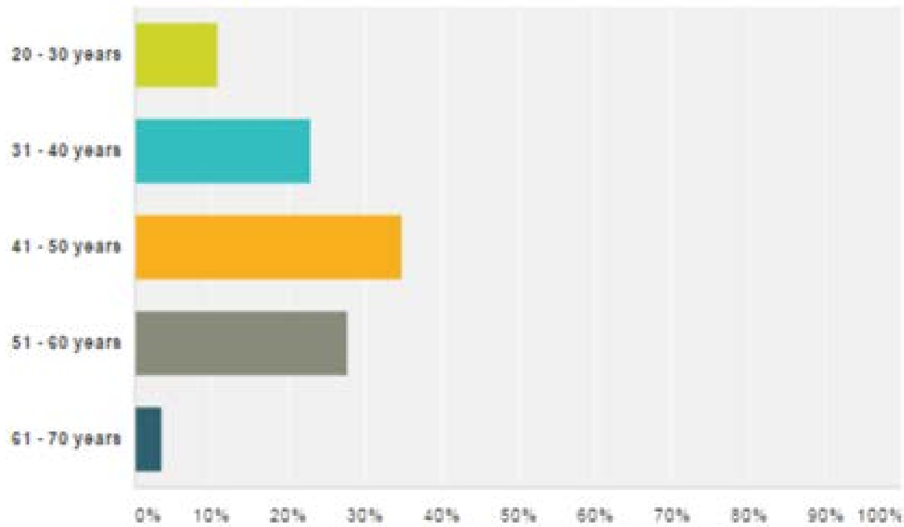
Type of school



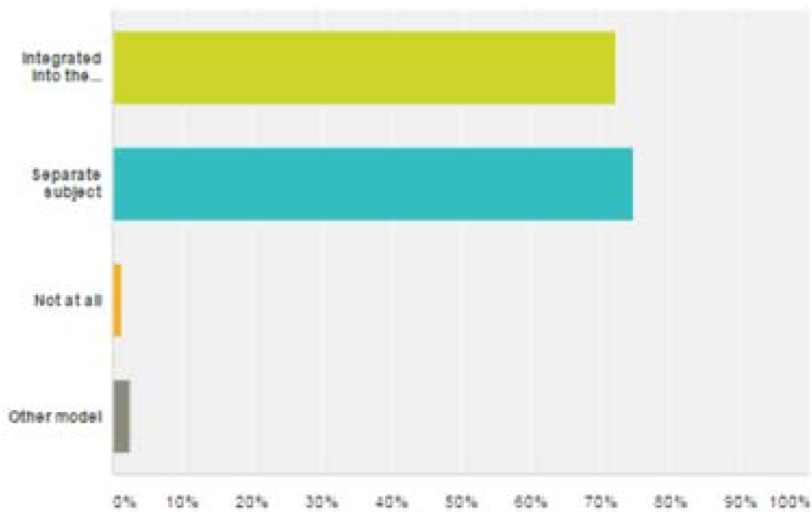
State in which respondents are teaching



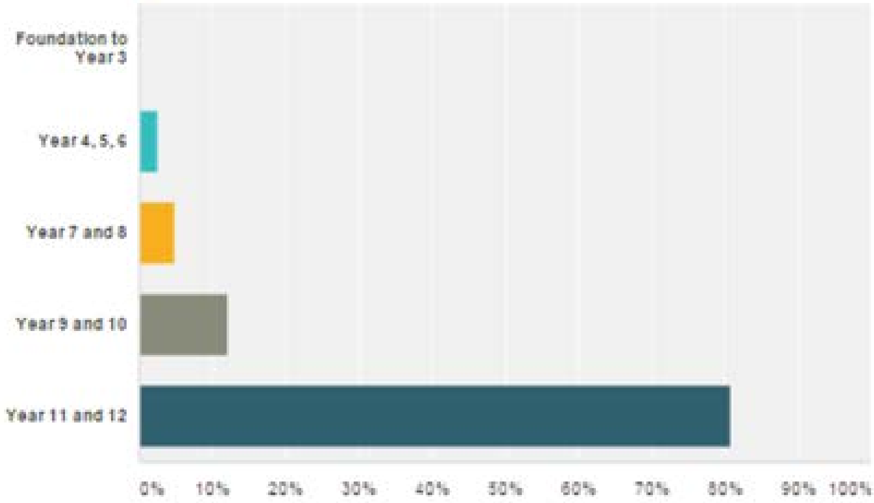
Age group of respondents



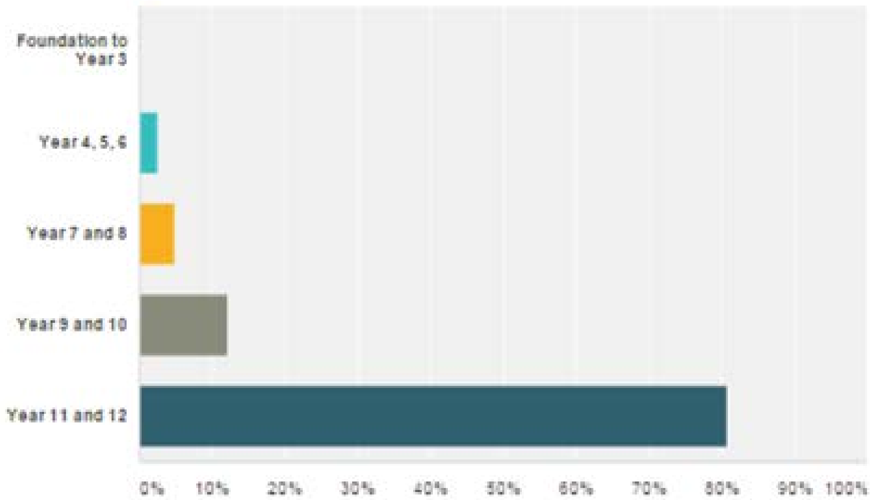
Chemistry is not always taught as a separate subject



To which age groups did respondents teach chemistry?



To which age groups did respondents teach chemistry?



Top five current challenges for chemistry teachers

• Lack of interest of students	35 %
• Not enough access to professional development	29 %
• Not enough chemistry teachers to talk to	24 %
• Poor quality of facilities	19 %
• Too large class sizes	16 %
• Not enough consumables	15 %
• Occupational health and safety risks too high	12 %
• Insufficient access to printed support materials	6 %
• Slow/poor internet connectivity/bandwidth	2 %
• Other challenges (combined)	25 %

Top ten ways to improve teaching at their school

• More teaching time, especially for prac sessions	13 %
• Moore teachers who are better qualified in chemistry	13 %
• More and better equipment & consumables	12 %
• More hands-on experiments	10 %
• More access to industry and industrial chemists	10 %
• More integrated resources (interdisciplinary)	8 %
• More Professional Development	8 %
• Better facilities	7 %
• More chemistry in years junior school and year 7-9	7 %
• Mentoring of young/generalist teachers by older chem. teachers	4 %

Challenges for chemistry teachers in the next decade

• Student retention (can deselect chemistry for easier subjects)	22 %
• Low chemistry skills of graduating chemistry/science teachers	19 %
• Student interest and attitude (learn to pass exams)	15 %
• Relevance of chemistry not clear to students	13 %
• Older teachers retiring	13 %
• Overcrowded curriculum with low relevance to real world	12 %
• Ability to update skills based on new chemistry research	12 %
• Chemistry job market, especially outside capital cities	11 %
• Funding and resource constraints	5 %
• Teaching time constraints for pracs.	4 %

Opportunities for chemistry teaching in the next decade

• More utilisation of ICT and modelling	17 %
• Improvements of curriculum	11 %
• New materials & technology provide relevance	8 %
• Better skilled young chemistry & science teachers	7 %
• Higher focus on interdisciplinary aspects of chemistry	7 %
• Improved access to Professional Development	6 %
• Cannot see any opportunities	7 %
• Not sure	10 %

Appendix 15 – Chemists in government survey

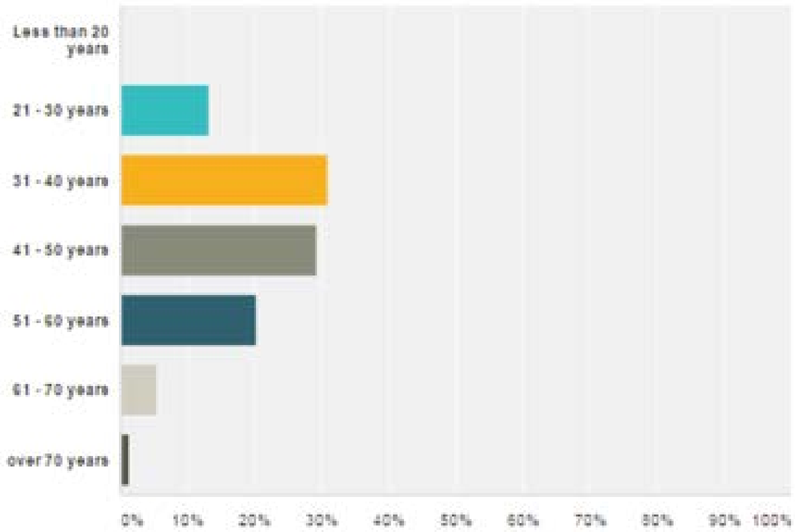
20-question survey July to November 2014
168 responses from 6 organisations

Survey respondents by organisations

	Number	% of respondents
• CSIRO, DSTO, ANSTO	148	89
• Government agencies*	20	21
• Male	125	74
• Female	26	26
• Tenured	130	77
• Fixed term	35	21
• Casual	3	2

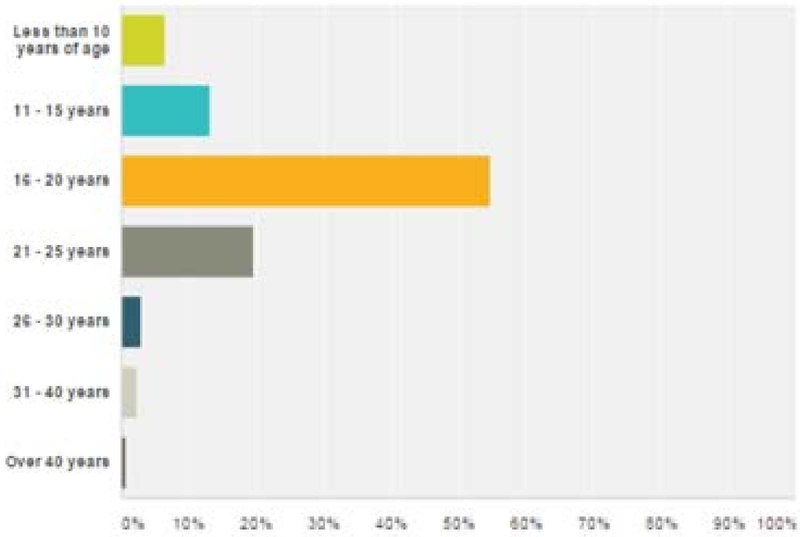
* EPA, TGA, FSANZ, IPA, Dept, of Health, DAFF, BOM, SafeWorkAustralia, ABS

Age group of respondents

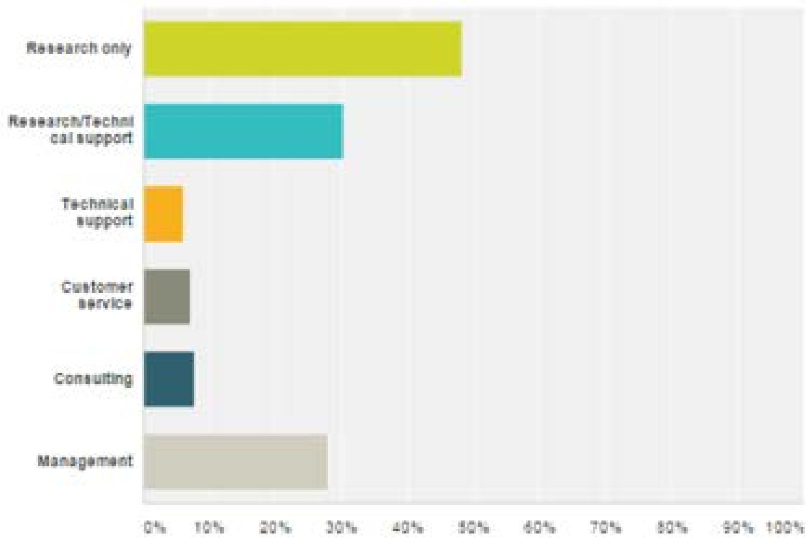


Chemists in government survey summary – © National Committee of Chemistry 2015

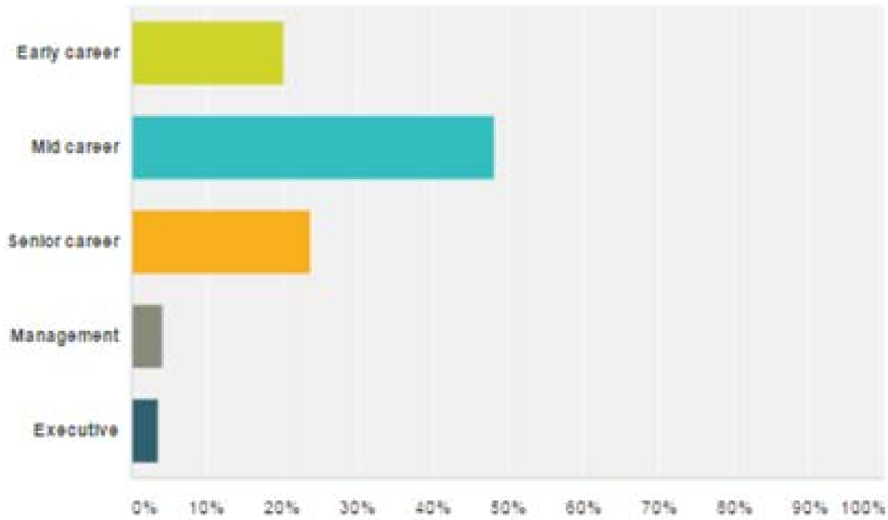
Age at which chemistry career choice was made



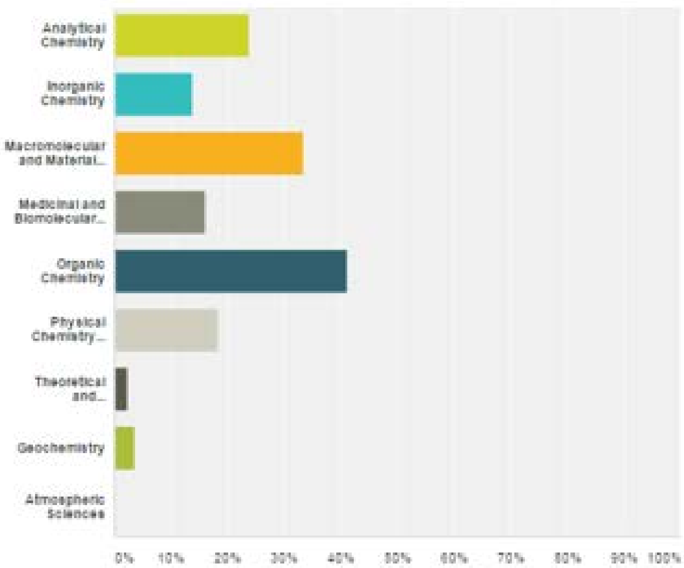
Current role



Current career stage



Predominant field of work



Past professional experience

- 48 % had worked overseas
- 45% had worked in industry or business
- 51% had worked in an academic institution

Past overseas experience

Geographic region	Respondents as % of respondents who have worked overseas
UK & Ireland	39.5
North America	24.7
Continental Europe (except Russia)	21.0
India	5.0
Japan	3.7
Rest of Asia	6.4
Middle East	2.5
South Africa	2.5
NZ	2.5
Russia	1.2
Uncategorised	13.6

Past overseas experience

< 1 year	5%
1 – 2.5 years	38%
2.5 – 5 years	29%
5 – 10 years	11%
10 – 15 years	7%
> 15 years	10%

Past experience in industry

Time in industry in years	Respondents as % of respondents who have worked in industry
< 1 year	7.0
1 – 2.5 years	42.3
> 2.5 – 5 years	21.1
> 5 - 10 years	18.3
> 10 – 15 years	8.5
> 15 years	4.2

Past roles in industry

Functional role	Respondents as % of respondents who have worked in industry
Research & Development	47.1
Analytical Chemistry	19.1
Quality control	7.4
Technical support	4.4
Process management	4.4
Formulation & optimisation	3.4
Environmental chemistry	2,9
Regulatory	2.9
Student intern	2.9
Production	1.5
Patent specialist	1.5
Other	7.4

Reasons for leaving industry

Reason for leaving industry	Respondents as % of respondents who have worked in industry
Found better opportunity	32.4
Company restructure	17.7
Personal reasons	13.2
Further study/qualification	11.8
Made redundant	8.8
Did not like industry	7.4
Missed research environment	5.9
Short term contract	4.4
Lack of career	2.9

Past experience in an academic institution

Time in a higher education institution in years	Respondents as % of respondents who have worked in a higher education institution
< 1 year	7.1
1 – 2.5 years	32.1
> 2.5 – 5 years	38.1
> 5 - 10 years	20.2
> 10 – 15 years	2.4
> 15 years	1.2

Reason for leaving academia

Reason for leaving academia	Respondents as % of respondents who have worked in academia
Found better opportunity	34.2
Contract ran out	25.3
Personal reasons	12.7
Further study/qualification elsewhere	3.8
Finished education/PhD	13.9
Did not like to be an academic	6.3
No research opportunity	2.5
No job available	3.8

Chemists in government survey summary – © National Committee of Chemistry 2015

Top ten challenges for chemistry professional in the coming decade*

- Job security/availability 39%
- Lack of funding 28%
- Declining industry 14%
- Image of chemistry 13%
- Government policy/strategy 13%
- Government science illiteracy 10%
- Career progression 8%
- Lack of research opportunity 7%
- WHS regulations 6%
- Availability of quality students 6%

*multiple challenges could be given

Chemists in government survey summary – © National Committee of Chemistry 2015

Top ten opportunities for chemistry professionals in the coming decade

• Opportunities are very limited	23%
• Biomedical/pharma/biotech	16%
• Alternative clean energy	13%
• New materials	10%
• Cross-disciplinary collaboration	8%
• Environment	7%
• Bio-based feed stocks	4%
• Nanotechnology	4%
• New technologies	4%
• Food and Agriculture	3%

*multiple opportunities could be given

The top three most important technical challenges for chemistry in the next decade

• Alternative , clean, renewable energy	50%
• Human health, drug design, delivery, resistance	36%
• Food security, agriculture, fertilisers, water	19%
• Climate change, CO2 management	18%
• Environment, sustainability, waste management	18%
• New materials, polymers, nanomaterials	17%
• Alternative and green feed stocks	7%
• Improved and green manufacturing processes	5%
• Synthesis	2%
• Catalysis	2%

* Respondents were asked to provide three technical challenges