CHEMISTRY

FOR A BETTER LIFE

The Decadal Plan for Chemistry

2016-2025

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

Foreword

Chemistry as a discipline has been and remains a significant contributor to the wealth, prosperity and health of the human species. Over the last 5,000 years chemistry, more than any other discipline and practice, has made our global civilization and prosperity possible.

But our world is changing in extraordinary ways bringing with it a host of opportunities and challenges for science and society. The principal question of course is, how can we support an ever increasing population of highly connected citizens, who all aspire to a high degree of material wealth, nutrition and mobility, with a finite amount of resources and energy?

Globally, chemistry will remain indispensable in positioning and responding to these opportunities and challenges. Australia is a very small but determined player, which contributes both to Chemistry as a science, discipline and is home to a significant chemical industry. It needs to be best positioned to take advantage of unprecedented global growth where chemistry is an enabler of economic, social and environmental prosperity. Our vision for Chemistry in 21st Century Australia is simple.

Chemistry - For a Better Life

"Inventing what matters"

This vision integrates and addresses both the new global opportunities for, and challenges to, humanity and Australia's own National challenges for members of the chemistry community engaged in research, teaching and industry. Each of these areas undertakes important work with a genuine interest in improvement and contribution to Australia's prosperity. However, there are a number of contextual complexities that make it difficult to focus limited investment of funding into Chemistry teaching, research and industry to ensure the delivery of significant national benefits via teaching, research and commercial application.

- The industry and discipline of chemistry in Australia is fragmented and represented by numerous entities that are not well aligned;
- Universities and numerous government research providers such as CSIRO are actively involved in R&D within the discipline, along with a range of chemical companies and Australian SMEs who actively support chemistry and rely on R&D and technology for growth and profitability;
- The teaching of chemistry from primary through to tertiary levels remains disjointed and there is a lack of a curriculum aligned to support the growth and development needs of the industry;
- And despite the positive contributions made by chemistry, the perceptions of Chemistry are not positive
- Governments are often unaware or uncoordinated regarding the contribution and capability chemistry brings to the economy or the most efficient policy settings that enable this capability to be invested in national prosperity.

The pathway presented in this Decadal Plan is the result of extensive and detailed consultation with stakeholders, to find the common ground that exists to support the discipline and practice of chemistry to benefit all Australians. It is primarily a bottom-up, community driven document, aiming to guide investment and effort in Chemistry research, education, industry and infrastructure.

In essence though, this report is for the children who are just 6 years old today. These children will be studying final year Chemistry in 2025. They will decide whether Chemistry offers attractive career options and whether it is a scientific discipline which offers real challenges and opportunities with sustainable jobs and well-defined and rewarding career pathways.

By President of AAS

Executive Summary

Unlike most other scientific disciplines, there is a continuum in chemistry that ranges from educations, basic research through to chemical manufacturing and the reliance on chemistry throughout the country's value-chains. This breadth is both a strength and weakness of the discipline and practice.

The challenge that continually confronts the discipline is the fragmentation of the different groups that form its key stakeholder base. These key stakeholders are:

- The primary/secondary education sectors;
- The tertiary education and research sectors;
- Government research providers (e.g. CSIRO, ANSTO, DSTO);
- The chemical industry and its value-chains; and
- Government.

The aims of these entities are not sufficiently well aligned and the R&D landscape is complex: there are not only Universities active within the discipline, there are numerous government research providers such as CSIRO and a wide range of chemical companies and Australian SMEs who actively support chemistry and rely on R&D and technology for growth and profitability.

Industry fragmentation is evidenced by the numerous bodies that represent the industry, the largest of which is the Plastics and Chemical Industries Association (PACIA). The academic interests of Chemistry are represented by at least two separate bodies:

- The Royal Australian Chemical Institute (RACI); and
- The National Committee for Chemistry of the Australian Academy of Science.

Additionally, there are State based science teacher organisations and a variety of chemistry sub-discipline groups.

An important aspiration of the Decadal Plan for the ten years to 2025 is to facilitate better coordination and communication across the sector and to find common ground that can support the discipline of chemistry in Australia to benefit all Australians – revealing itself in improved economic, social and environmental prosperity. .

Vision

The Decadal Plan Working Group developed the following Vision:

"Chemistry for a better life – inventing what matters".

In an increasingly competitive global industry, this vision will guide Australian investment and activity to add to the global body of chemistry knowledge and efficiently deliver knowledge and improved products and services for national and international markets.

Research and Consultation

The strategic position as defined by the 1993 Chemistry review, current government science and funding policy as well as several industry and research organisation strategic plans were accepted as the current baseline position of Chemistry research, teaching and industry.

From this baseline position, the current state of Australian chemistry key stakeholders was evaluated in broad terms. This, combined with the desktop research completed, enabled the sector to be evaluated in the context of emerging global trends.

Analysis was focused on the following:

- How well the secondary education and higher education sectors are delivering the educational outcomes that are needed in the face of anticipated world changes and trends.
- How well research providers are delivering the research ideas and intellectual property required to enable the sector to be competitive in the future.
- How effectively the chemistry stakeholder community interacts so that it can adapt to future trends and changing needs and requirements.
- How participants in chemistry discipline and practice are planning and coordinating their work to facilitate improvement.

The consultation process revealed:

- International commercial and social trends, threats and challenges to the industry.
- Impediments to interactions between the sectors.
- Sector specific and sector spanning issues that are impeding efficiency.
- Current and specific requirements that need to be addressed to facilitate growth.
- The existence of considered strategic and forward planning work already in place and able to be adapted to, and strengthened by, broader engagement.

Opportunities identified

An example of strategic and forward planning is the PACIA Strategic Industry Roadmap. This was launched in 2014, following two independent reports commissioned by PACIA and the then Commonwealth Department of Industry. CSIRO's research analysed the current state of the chemical industry as well as identifying global megatrends the industry could take advantage of as well as the market growth areas and the industry enablers that might be employed. PACIA responded to this research with the Roadmap document "Adding Value – the critical, enabling role of the chemicals and plastics industry for Australia's future". The roadmap documents the following set of prioritised, coordinated actions between industry and governments to address industry contraction and facilitate sustainable growth:

- Urgent /short term: Access to natural gas for feedstock and energy; balanced regulatory environment; competitive capital.
- Strengthen /Medium term: Social licence to operate; Innovation and strong intellectual property; Strong customer base; Skilled and productive talent.
- Maintain /long term: Stable financial and political systems.

Challenges Identified

Industry competitiveness

- There is sub-optimal "value chain thinking" amongst chemistry stakeholders and limited awareness of the various ways issues in one sector can negatively or positively impact performance in other sectors.
- Although it is an essential contributor to the chemistry community, Government does not recognise its importance to the productivity of each sector and to the industry as a whole.
- Key stakeholders agree that translation of research outcomes into products, processes and services is inadequate and needs to be addressed as a matter of priority on a much bigger scale than current Government policy envisages.
- Poor policy and regulatory development, attributed to the very low science literacy of policy makers and the general public has a strongly negative impact on the competitiveness of all sectors of the industry and its 'customer' industries.

The general public

- Australia has a very low proportion of citizens who are scientifically literate, with a background in science or technology (STEM subjects). There are few leaders that are able to understand the implications of technical innovation.
- Chemistry has a poor image in the population, and this perception is developed at a very young age.

School education

- School students are forced to make uninformed career choices because collectively teachers, parents and students have insufficient knowledge about the relevance and benefits of chemistry to society and the career opportunities it presents.
- Many high school chemistry teachers and primary school teachers do not have sufficient domain expertise in chemistry to provide passionate teaching and facilitate inspired learning.
- Students can deselect Chemistry at school and yet still enter Science/Chemistry undergraduate degrees, meaning the higher education sector has to provide bridging courses to students.
- There is often limited infrastructure and capacity to provide practical Chemistry experience in schools in disadvantaged, remote and regional locations, which limits access to study chemistry and the quality of teaching for those that do.

Higher education

- The number of students electing to do STEM subjects at school, including Chemistry, is declining.

- There are serious issues facing smaller regional universities due to the 'flight' of good school leavers to the capital city universities. This is resulting in a wide disparity of quality of Chemistry courses and graduates across Australia.
- There are no mandatory, minimum entry requirements for Chemistry courses at universities.
- There is no agreed and uniform university curriculum. This makes it difficult for current and future high school teachers to lift the standard of school Chemistry teaching.
- Staff: Student ratios are becoming increasingly unfavourable, leading to poorer teaching outcomes.

Academic research

- Due to the heavy reliance on ARC funding, the sector focuses on 'run of the mill' research and does not embark on more ambitious and higher risk research that could be the basis for future high-end innovation in the Australian industry.
- There is disenchantment in the sector amongst young researchers because of poor career prospects.
- The focus on ARC research funding is a disadvantage for women in the academic sector, and does not support greater gender balance in higher level academic positions.
- The lack of funding options for chemistry outside the ARC, the low chance of funding and the time burden associated with applying for ARC grants is substantial and leads to low research efficiency and productivity in chemistry.
- Universities lack the resources and capabilities for demonstrating the value of their research to industry.
- Chemistry departments have a poor track record of translating their research into new products via start-ups or industry collaboration.
- Chemistry researchers are not rewarded for interaction with industry and believe such interactions actually penalise their careers.

Government research

- Disenchantment within a large proportion of government research organisations means highfliers leave for overseas positions, reducing Australia's innovation capability.
- There is poor delineation between basic research and strategic research and there is both unnecessary competition with the academic sector and duplication of effort.
- Schedules for delivery of research to industry are "unviable" because of the other management and administrative workload responsibilities that fall to researchers.
- There is duplication of agencies for commercialisation and funding, leading to reduced research efficiency.

National large research facilities

- There is concern within the Chemistry research community about future funding and upgrading of the main large research facilities and related infrastructure.
- There is concern about the availability of funds to undertake research at these facilities.

Australian Chemical industry

- There is low awareness of the potential of patentable innovations to drive industry competitiveness in a global, carbon-constrained environment.
- There is poor understanding of the capacities and capabilities of Australian research providers.
- Small industry companies are disadvantaged in their interactions with R&D providers.

Winds of change –opportunities and threats for the global and Australian Chemistry industry

A number of global megatrends, threats and risks were identified during consultation that present both major challenges and new opportunities for the industry:

- Population growth and demographic shifts.
- Economic power shifts.
- Climate change, resource scarcity and declining sustainability.
- Technology driven economic change.

National Challenges for Chemistry

The decadal plan has identified an additional list of ‘Ten National Grand Challenges’ for chemistry that focus the potential of the discipline into useful outcomes for society. However, new knowledge will be needed and consequently, it is critical that a world-class cohort of chemistry researchers is supported, who can explore the fundamental limits of the science,.

1. Agricultural productivity increases.
2. Conservation of scarce natural resources through alternative materials and new processes to extract valuable materials from untapped sources.
3. Conversion of biomass feedstock through the development of bio refineries, using different types of biomass to provide energy, fuel and a range of chemicals with zero waste.
4. Diagnostics for human health to enable earlier diagnosis and improved methods to monitor diseases.
5. Drinking water quality improvement through new technologies to provide clean, accessible drinking water for all.
6. Drugs and therapies to harness and enhance basic sciences to transform drug discovery, development and health care, delivering new therapies more efficiently and effectively.
7. Energy conversion and storage improvements (e.g. fuel cells and battery technologies).
8. Nuclear energy and its safe and efficient harnessing, through the development of fission and investigation into fusion technologies.

9. Solar energy technology improvements that yield more cost efficient processes and the development of the next generation of solar cells to realise the potential of solar energy.
10. Sustainable product design that takes into account the entire life cycle of a product during initial design decisions to preserve valuable resources.

Strategic Goals

Strategic goal 1: Raise chemistry knowledge and skills in the chemistry stakeholder community.

Strategy 1.1 - Improve Chemistry education in Primary and High Schools

- Set a minimum pre-requisite of a Bachelor of Science degree with major in Chemistry for high school teachers who teach above year 8/9 level Chemistry. More highly qualified Chemistry teachers will enable better engagement and teaching outcomes for students. If industry placement during the undergraduate degree is one of the features of a Chemistry major, then teachers will be able to portray better how Chemistry can lead to a valued career for students.
- Set a minimum standard of 1 science trained teacher preferably with a BSc graduate level or at least year 12 Chemistry/Science qualification for every Primary school to ensure they can portray science and present Chemistry principles and knowledge in an appropriate way.
- Enable all high schools to offer modern practical experience in Chemistry and develop better models for providing practical Chemistry experience to high school children in regional and remote areas and in disadvantaged schools, potentially through networked schools or by improving the logistics of access to chemistry teaching infrastructure.
- Promote Chemistry teaching careers at all universities - ccurrently, the career path of a Chemistry or Science teacher is not sufficiently promoted at universities. Students are generally directed towards an academic or research career first, an industry career second and only into teaching as a last and less desirable option.
- Improve the image of Chemistry teaching as a career - the image of Chemistry teaching as a career is currently poor and there is a need for a targeted and sustained activity in promoting Chemistry as a whole and Chemistry teaching in particular.
- Support ongoing Professional Development of Chemistry teachers and interaction with universities to ensure regular updating of knowledge, teaching techniques and keeping abreast of the field and develop accessible PD opportunities for remote teachers.

Strategy 1.2 - Improve Chemistry education in Academic Institutions (universities)

- Mandate as a minimum entry standard into university undergraduate degrees the successful pass of an agreed Year 12 National Chemistry curriculum and Year 12 Maths.
- Agree a common National Chemistry Curriculum that is accepted by all universities.
- Mandate stricter professional accreditation of chemistry degrees in Australia.
- Develop an agreed skills and capabilities profile for Chemistry course and training providers and confirm mechanisms for external quality assessment (e.g. Government/industry) to ensure course curricula and generic attributes (transferable and practical skills, as well as industry placement opportunities) are met to an acceptable standard.

Strategy 1.3: Improve the Chemistry knowledge of policymakers and the general public.

- Mandate that every school leaver has an age-appropriate knowledge of Chemistry and/or Science to ensure that no school leaver will be completely chemistry/science illiterate.
- Develop an agreed outreach program for policymakers that enables the Chemistry community to provide information on important Chemistry related issues that will in turn enable informed discussions, decisions and policy development at all levels of government.

Strategic goal 2: Improve the capabilities of the research sector

Strategy 2.1 Address the National Challenges of the 21st century which fall within the purview of the Chemistry Sciences:

- Develop a set of research priorities that are tri-annually agreed by all sectors of the value chain.

Strategy 2.2 Focus Australian chemists to address more disruptive chemistry questions and the Grand Challenges of the chemistry discipline.

- Work with funding agencies to ensure that basic, strategic and applied research are all being carried out at the highest level, without conflicting goals and expectations. A clearer understanding at all levels is needed between the aspirations of researchers and the expectations of funding agencies.

Strategy 2.3 Maintain and consistently upgrade large research infrastructure to support Australian research at an internationally competitive level

- Consistently maintain and upgrade existing large infrastructure so that it becomes a focus for Chemistry based research in the Asia-Pacific region.
- Improve productivity of large and medium sized research infrastructure.
- Develop a National Chemistry Research Infrastructure register, that includes important medium sized infrastructure and make it accessible to researchers across the country and industry companies.

Strategy 2.4: Develop more diversified mechanisms for funding and conducting research in the academic research sector

- Develop a broader variety of funding sources for more directed research in order to address the more practical aspects of solving the Grand challenges of chemistry and provide (practical) solutions to the effects of the global trends, risks and threats. This will need to include novel ways to access funds from parties external to Australia.
- Change the reward and promotion structures in academic research institutions to reward industry engagement, IP creation (patents) and translation. This will require agreed new IP models and translation mechanisms throughout Australia and with all R&D providers, government and the research funding agencies.
- Incentivise stronger R&D investment of industry in academic institution based R&D to enable increased investment by industry and especially the SME sector in Chemistry research.

Strategy 2.5: Streamline and delineate the Government research sector from the academic research sector to enable better fit with value chain needs and faster delivery of unique products.

- Clearly define and delineate between core strategic research in the national interest that should be taxpayer funded, and R&D that is for commercial benefit and should be funded by industry. This delineation should be as clear as possible and supported by appropriate funding arrangements. Fundamental research should focus on areas where scale and teams are needed, which is where Universities generally do poorly.
- Develop mechanisms that can provide better R&D services to international, large national companies and SMEs. These mechanisms should take into consideration current funding constraints of both providers and industry segments.
- Develop models to enable SMEs to develop into more advanced Chemical companies that deliver higher value through innovative products.

Strategic goal 3: Raise the level of research and innovation efficiency and improve the translation of research outcomes

Strategy 3.1: Improve innovation capability of the academic research sector to enable faster and more targeted delivery of research outcomes

- Develop and incentivise better mechanisms for research translation that benefits all parties at the outset. Current mechanisms have drawbacks for both industry (lack of speed and high cost) and the academic sector (limitations on ability to publish, directed research, project management based research process). Better mechanisms are needed to increase the speed with which research outcomes are attained in order to improve research productivity.
- Improve the delivery times of R&D outputs to industry (become faster in delivery and improve interactions with customers and other parts of the Chemistry value chain).

Strategy 3.2: Develop mechanisms and processes for lifting the innovation capability, productivity, competitiveness and adaptability of the Australian Chemical industry

- Develop a pilot scheme (e.g. along the lines of the Swiss CTI model with innovation mentors who are specialized in supporting both Chemical industry technology development and start-up companies). This model would enable the matching of industry company needs with research provider capabilities to address specific needs and deliver high tech or high end competitive results fast.
- Develop processes and mechanisms for building more formal and long lasting relationships between industry, the higher education sector and research providers. This should focus on demonstrating and realising value for industry and research providers. The process should be largely driven by independent industry participants to ensure focus is on new products or processes and on productivity, effectiveness and results.

Strategy 3.3: Improve the effectiveness and efficiency of interaction and communication throughout the Chemistry value chain

- Improve the interactions and communication between all sectors of the Chemistry stakeholder community. Currently each sector has their own affiliation banner to which they belong (e.g. PACIA for industry, RACI for Chemistry researchers, ATSE and others). A more integrative approach is needed to facilitate communication, interaction and a common response of the Chemistry value chain to issues and threats.

- Develop and agree on a common communication plan for the complete value chain. Currently all sectors have their own plans, developed with very little consultation between sectors and this needs to be improved for delivering long term benefits. The goal is to limit confusion within and outside the value chain and to enable a unified response to issues and problems.

Strategic goal 4: Improve the image of Chemistry

Strategy 4.1: Promote Chemistry to the general public and portrait a positive and realistic image of its value to society

- Develop and fund an agreed media strategy to enable a constant media presence in the major media to provide frequent information about positive Chemistry results and the value of Chemistry in general. In contrast to many other science disciplines, Chemistry is almost absent in many media. For example news about new planets, the successes of space science, biology, medicine and biotechnology are highlighted every week, often several times on multiple media platforms. Chemistry is absent from the spectrum of news items. To address this a structured approach is needed.
- Develop and implement an agreed and nationally coordinated outreach program and ensure that every school in Australia has physical contact at least once a year with a Chemistry scientist or industrial chemical professional. There is currently no national strategy on how to deliver an effective chemistry outreach program to schools. Most Universities work on outreach independently and with little coordination.
- Develop mechanisms for access by individuals of the general public to Chemistry professionals. This could be in form of a "find a chemistry expert" scheme that ensures that anyone can find access to a chemical expert to get answers to Chemistry related questions. This is particularly important for assisting media driven enquiries.

Strategic goal 5: Enable implementation of the Decadal Plan

Strategy 5.1: Set up and fund a Decadal Plan implementation committee that represents and focuses on the interests of all segments of the Chemistry stakeholder community

- Appoint a committee with members from all sectors of the value chain and develop appropriate terms of reference.
- Source funding for the operations of the committee.
- Develop reporting mechanisms, KPIs and milestones, including a mid-term review for the committee.
- Develop a budget for the implementation plan.

Strategy 5.2: Develop a common value chain roadmap and a long-term rolling strategic research and development plan to facilitate its adaptability to global, regional and national threats and opportunities.

This is expected to be part of the remit of the Decadal Plan implementation committee.

Implementation

Implementation of the Decadal Plan strategies needs to progress in the most efficient way possible.

For this purpose, implementation will require oversight of the development and execution of a full implementation plan. Working groups with different skill sets will be required to accomplish speedy progress towards implementing clusters of strategies.

There are five distinct modules that, even though there are interdependencies between them, can be implemented in parallel over time.

These modules relate to:

1. Establishment of the implementation committee and its working budget, KPIs, TORs, funding, and issues involved with further adjustment of the strategic direction.
2. Redefining the education of Chemistry, both in the school and the higher education sector.
3. Improving the working relationship and efficiency between industry and the research sector. Part of this implementation module is the development of a common value chain roadmap and R&D plan, incentivisation of research provider interaction with industry and the proposed innovation mentorship pilot scheme.
4. Improving the research efficiency in terms of defining clearer priorities, improving infrastructure productivity and developing a better risk balanced research portfolio.
5. Development of a media strategy and a Chemistry expert access program.

A full implementation plan detailing human resource requirements and operating budgets should be created by the Implementation Plan Committee.

Key risks and dependencies

Implementation of the Decadal Plan strategies needs to take into account the interdependencies between the recommended strategies. There are clear and specific linchpins in the strategic framework, that need to be implemented thoughtfully, efficiently and effectively because of the many other strategies that depend on their effective implementation. These linchpins, if not implemented successfully, will represent substantial risks to the success of the Decadal Plan.

The two, most critical, strategic linchpins are (a) the development of a common roadmap with a rolling R&D plan that supports successful adaptation and response of chemistry research, teaching and industry to emerging threats, challenges and opportunities, and (b) the appointment of a Decadal Plan implementation committee with suitably qualified members that are able to work towards common goals.

Two other substantial risk areas are (a) getting agreement by research providers and industry on a risk-balanced research portfolio and (b) elimination of research translation hurdles. If agreement on new and mutually beneficial price/cost models cannot be developed, collaboration between the research sector and industry will not succeed.

A third area of risk is the ability to reach agreement on education goals in the primary, secondary and tertiary education sectors. This will depend on buy-in by other stakeholder sectors, and especially by industry.

Opportunities

This decadal plan is being formulated at a crucial time for Australia. The economy needs to transition from its mining boom focus to a better balanced, forward focused manufacturing base. Australia needs to re-invigorate key areas of the manufacturing sector and chemistry is one of the most promising areas for investment. Australia offers

- a vigorous chemistry education system,
- an internationally competitive R&D sector and
- a cohesive, well-networked marketplace for new products.

Australia has the capacity to develop new chemical products and can easily match its Asian neighbors in design, innovation and product quality. Supporting the goals of the decadal plan will help advance Australia's move towards more sophisticated, value-adding products, and implementing the plan will drive the expansion of a manufacturing sector, which is crucial for the evolution of other emerging sectors such as the nascent biotechnology and biomedical devices sectors.

The decadal plan is the first step in advancing Australia's most important, value-adding manufacturing sector. It identifies the key challenges, blockages and opportunities for Australia in the 21st century and proposes solutions that can help the sector reach its potential as a world class, international manufacturing hub. The following recommendations therefore aim to establish community acceptance of these goals, requirements and strategies. The recommendations envisage the formation of a broad, high-level implementation committee that will develop the policies, mechanisms and funding channels needed to realise the longer term requirements of the stakeholders.

Recommendations

Recommendation 1: Australia must continue to invest in maintaining the vitality and strength of its chemistry sector, which underpins the vast majority of the manufacturing sector of the Australian economy.

Recommendation 2: This Plan urges the Australian chemistry community to seek stronger differentiation and focus of both its research and commercial products. This will enable the Australian industry to be competitive in the global market through different and better outputs including niche products for special Australian market needs, but also through distinctive and unique manufacturing processes and higher quality services. Australia must differentiate on quality, but must also be pro-active in seeking new areas and markets to develop.

Recommendation 3: The Australian Government should accept the strategies outlined in the Decadal Plan. These strategies will help to create a more connected and cohesive Chemistry community, and will support the development of Chemistry as Australia's most significant value-adding industry.

Recommendation 4. The Australian Government together with the Australian chemical industry, the large R&D sector and the broad chemistry education system should establish a Decadal Plan

Implementation Committee, which has agreed Terms of Reference, the authority to develop appropriate budgets and sufficient funding to oversee the implementation of the draft strategies.

Recommendation 5. As part of its charter, the Decadal Plan Implementation Committee should be required to undergo a mid-term review of its progress in 2020. The review committee should consist of stakeholders from across the sector as well as external Government representatives.

In the following section we outline how we believe the recommendations can be acted upon, so that the goals of the chemistry community can be attained.

The Way Forward

At a glance:

- The strategies outlined in this Decadal Plan are intended to achieve greater cohesion and connectivity across the chemistry sector, and to support each segment of Australia's largest industrial value chain;
- An Implementation Plan will be developed by a Committee drawn from stakeholders in the Chemistry community;
- The work of this Committee must be actively supported by the wider Chemistry community in order to have the appropriate authority to develop and oversee the implementation of the strategies in this Decadal Plan;
- A mid-term review of this Decadal Plan in 2020 will be used to assess progress, analyse outcomes and determine necessary changes.

The Chemistry Decadal Plan is a vision for the future of Chemistry. Based on ideas and contributions from the entire Chemistry community, it aims to guide the development of the discipline over the next ten years. The Plan outlines a number of strategic goals that will significantly improve opportunities for chemistry in Australia in the industrial and academic spheres.

This plan belongs to us, the Australian Chemistry community. It represents our aspirations and ideas, our challenges and opportunities. We must recognise that responsibility for its success lies with us – every person and organisation involved in Chemistry in Australia. We must support it, we must commit to it and we much contribute to its implementation in order to realise the benefit that will flow to everybody involved in the Chemistry value chain.

Implementation of the Decadal Plan will be a challenging endeavour that will require the active support of the entire Chemistry community. That is why we must commit to working together as a community to implement the Plan. We must be able to speak with a united, respected and persuasive voice. It is up to us to persuade policy-makers and other important stakeholders that our ideas represent significant opportunities for Australia and its prosperity.

We must show the community the value of Chemistry in Australia. We must show the community how chemistry underpins significant economic benefits in the manufacturing sector now, and how it provides opportunities for a better life for future generations of Australians. We must share our successes with the community. We must show that Australia differentiates on quality, and is proactive in seeking new areas and markets to develop.

We must work to persuade the Australian community, through business and governments, to maintain the vitality and strength of the Chemistry sector. We must encourage business and government in Australia to be bold in seeking new opportunities for chemistry to further enhance our economic, social and environmental well-being. We must work to ensure that Australian chemistry is world-leading in its areas of strength, and is seen as such. We must make the Australian Chemistry sector the natural home of the highest quality Chemical research, expertise, goods and services.

The next steps

In late 2015 and early 2016, the Chemistry sector will come together to form a group of high-level representatives to translate this Plan into action. The Implementation Committee will be drawn from representatives of industry, education and academia and will take on the task of developing an implementation plan that will identify specific initiatives and opportunities to progress towards our strategic goals.

- Within two months of constitution, the Committee will have developed its enabling framework (terms of reference, meeting schedule, secretariat support arrangements, final composition)
- Within six months of constitution, the Committee will have developed a draft implementation plan
- Within twelve months of constitution, the Committee will have developed a draft set of specific initiatives to operationalise the implementation plan.
- Within eighteen months of constitution, the Committee will have connected proposed initiatives with the necessary leadership, stakeholders and resources to enable their implementation.

The success of the Implementation Committee will depend on active support from the Chemistry community to:

- Directly support the work of the Committee
  - Provide high-quality, constructive input to the Committee's work
  - Provide time, expertise and resources to the work of the Committee where appropriate and available
  - Actively identify opportunities for the implementation of the Plan in our own networks and workplaces
- Build a critical mass for the Decadal and Implementation Plans:
  - Create awareness about the work of the Committee and the progress of the Plan with our colleagues, managers, stakeholders and professional associates

  - Engage with our peers with our ideas for the Plan
  - Strengthen the voice of Chemistry by taking part in sector-wide initiatives to engage with business, government and the wider community
- Create a cohesive, committed and respected Chemistry community
  - Commit to forging Chemistry relationships outside of routine activities
  - Commit to connecting students and junior colleagues with the Chemistry community, through industry bodies and professional associations
  - Commit to promoting a culture of collaboration throughout the sector
- Assess, evaluate and improve the plan
  - Initiate and contribute to a mid-term review of the progress and strategies of the Decadal Plan and the Implementation Plan in 2020.

By working together as a united community, the Chemistry sector has the opportunity to realise the vision and the objectives set out in its Decadal Plan. If the Implementation Committee has the community behind it, its ability to influence business, government and stakeholders will be greatly magnified. If we can engage the networks and resources of the entire community, then we will be better able to turn ideas into actions. If we can work together to help implement the Plan, then we will discover new opportunities to further strengthen our sector.

Australia must continue to invest in maintaining the vitality and strength of its Chemistry sector. The Decadal Plan offers the tools to the leaders of the Chemistry stakeholder sectors to make this possible.

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Chapter I – Background and Introduction

The proposal to undertake construction of a Decadal Plan was an initiative of the Australian Academy of Science in 2013. The proposal was embedded into the terms of reference for the National Committee of Chemistry of the AAS in mid-2013 (Appendix 1).

The Terms of Reference (Appendix 2) for the Decadal Working Group were defined as follows:

- To consult widely throughout all sectors of the chemistry value chain*, from the primary school sector, through higher education, the research provider sector, regulators to industry and government policy makers.
- To provide strategic science policy advice, to the Academy, as input to Academy science policy statements, and (with the approval of the Executive Committee of Council) to the Australian Government and Australian organisations.
- To connect the Academy to chemical science and scientists in Australia.
- To ensure that Australia has a voice and a role in the global development of chemistry.
- To facilitate the linkage of the Academy to all sectors of the Chemistry value chain in order raise the relevance and viability of chemical science and to promote the development of the discipline.
- To facilitate the alignment of Australian chemical science to the global chemical science community and global scientific goals.
- To produce a decadal plan document for chemistry in Australia.
- Produce an implementation plan upon acceptance of the strategic direction of the Decadal Plan.

The process undertaken to create the Decadal Plan and to arrive at a set of strategic options, implementation options and recommendations followed a number of steps (Figure 1).

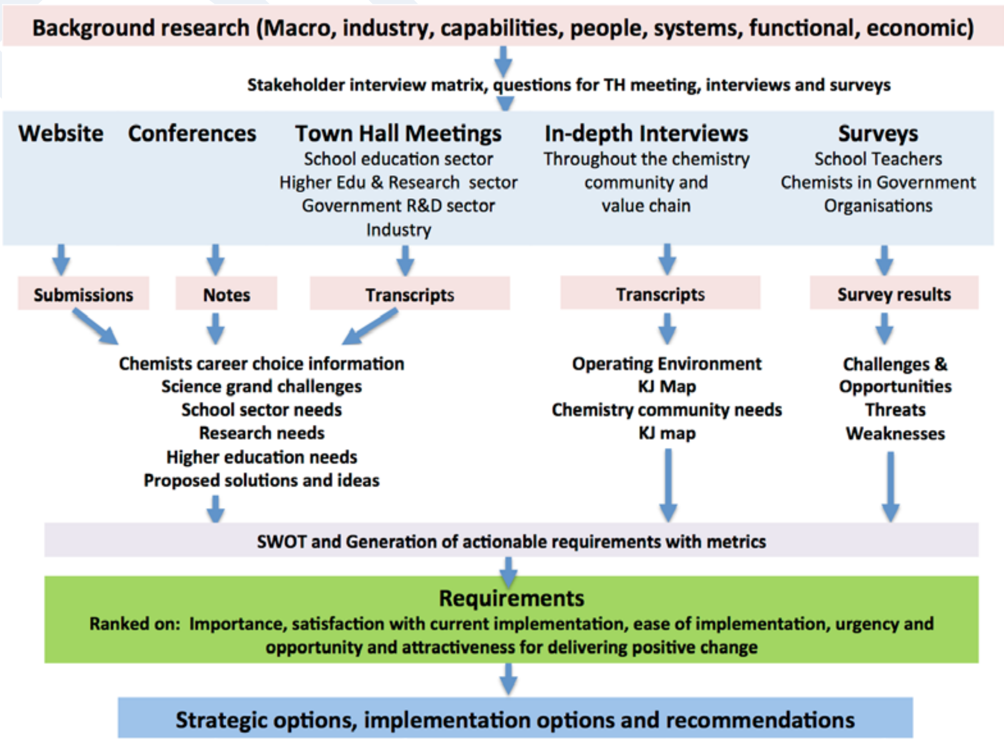

Figure 1: Decadal Plan Process

A potential list of working group members was drawn up in January 2014 and the final composition of the working group was finalised in March 2014. The WG was drawn from major stakeholders in the different states of Australia, different subsets and specialisations within the field and included representation from industry through PACIA and from Government research providers CSIRO as well as high school representation. (Appendix 3) and universities offering chemistry degrees (Appendix 4).

The Decadal Plan Working Group employed a general business planning approach to its stakeholder consultation, analysis and strategic planning and undertook an extensive program of research and consultation to understand the chemistry value chain in Australia, its challenges and requirements and to rank them according to importance and priority (Appendix 5, 6, 7, 8 and 9).

This analysis was used to develop the strategic directions, goals and recommendations presented in this Decadal plan. The goals identified were then used as the key inputs for the development of a high level implementation plans.

Extensive consultation has been a feature of the development of this plan. However, there are numerous structural and stakeholder barriers to its successful implementation and the key stakeholders in the chemistry value chain will need to work collaboratively to ensure that the benefits envisaged from the Decadal Plan process can be realised for the benefit of all.

Chapter II - Chemistry in Context

Chemistry is the science of molecules, the basic building blocks of matter and the world around us. Chemists have shown that all the substances around us, the earth and indeed the Universe as a whole are composed of 92 building blocks or elements[1]. In fact, just 20 of these fundamental elements are responsible for more than 99% of the world we see around us.

In sharp contrast to other major science disciplines such as Physics, Mathematics and Biology, chemistry is the only 'fundamental' science that has a specific industry attached to it.

The Global Industry

In 2014, the global chemicals industry contributed 4.9% of global GDP[2]. When the 2006 RACI Chemistry business report was released, the global chemical industry had revenue of $US1.7 trillion dollars. A decade later, the gross revenue is $US 5.2 trillion dollars[3]. That corresponds to $800 for every man, woman and child on the planet.

The largest market for chemical industry outputs is now Asia – where the share of the global chemical industry revenue has grown from 40.9% to 54.2% over the same period.

Combined revenues for the Global Top 50 chemical firms increased 1.7% to $980.5 billion in 2013[4]. The top 10 Chemical companies in the world had a turnover of USD 429 billion in 2014.

Innovation in the Global Chemical industry is mostly driven by the innovation plans of the largest companies and by the innovation policies of the major production regions and countries such as the EU, the USA, and some of the major Asian countries. Countries with the highest innovation intensity are the USA, China, the EU, Japan and Switzerland. China and India are emerging as large investors in Chemistry R&D.

Many of the large Chemical companies re-invest a substantial proportion of their sales revenue in their R&D projects and facilities. Some of these are increasingly diversified and located close to, or in, their major customer markets and manufacturing countries. As a result, most international Chemical companies have been moving their R&D capabilities out of Australia, leaving only customer service and some minor manufacturing capacity in Australia.

Why Chemistry Matters

Chemistry as a discipline has been and remains a significant contributor to the wealth, prosperity and health of the human species. Over the last 5,000 years, it is chemistry, more than any other discipline, which has made our global civilisation possible.

[1] There are in addition some 15 artificial but unstable elements that have been synthesized.

[2] Cefic Chemdata International – The European Chemical Industry Council (2014) report

[3] http://www.statista.com/statistics/302081/revenue-of-global-chemical-industry/

[4] http://cen.acs.org/articles/92/i30/CENs-Global-Top-50-Chemical.html

The TV documentary series “The Ascent of Man”[5] charted the correlation in human prosperity through the chemical discoveries that led to technological revolutions in our past - from Stone Age, to Bronze Age to Iron Age and hence to steel, plastics, petroleum, silicon, DNA and most recently graphene.

Early civilisations learned how to extract simple metals and to process them, which enabled military and eventually economic superiority. Likewise the civilisations that discovered gunpowder gained ascendancy in many areas of the globe. Innovations such as the development of specific cements, mortars, and later on, concrete, glass and plastic allowed urbanisation on a massive scale and to larger, longer lasting buildings. The industrial revolution was enabled by the rapid improvements in understanding combustion and thermodynamics of fossil fuels and consequently this led to global power shifts to countries which were able to implement these innovations on an industrial scale.

Table 1: A few of the many Chemistry inventions during human history

Period	Discovery	Impact
Stone Age 12000 - 4000BC	Development of Agriculture	Humans stopped being nomadic and could settle into villages.
5000 BC	Discovery of glass probably as side product from copper or tin smelting.	Used in architecture, cups and jewellery and nowadays in all transport and buildings.
Copper Age 5000-3500 BC	Discovery of copper	First metal tools produced
Bronze Age 4500 BC	Alloying of copper and tin produced harder metal - bronze	Trading of Bronze and Tools - Technology Transfer, stronger weapons.
Iron Age 1200BC	Hot Smelting and Furnaces needed for recovering and working the metal	Superior weapons to earlier bronze weapons.
	Invention of concrete/mortar	Urban development
	Invention of bitumen	Allowed proper roads to be built
	Invention of gunpowder	Enabled guns and cannons to be developed.
1791 -Lavoisier, Scheel and Priestley	Discovery of oxygen - first element to be isolated since the natural occurring ones known since Roman times.	Allowed the nature of combustion to be clarified. Metabolism in living creatures shown to be a type of combustion.
1804-1811 Humphrey Davy	Using electrolysis Humphrey discovers 7 elements.	Established the link between electricity and chemistry.
1871 - Dmitri Mendeleev	Mendeleev conceives the idea of a periodic table of the elements based on similarity and recurrence of properties.	Recognition that all substances are made from combinations of indivisible building blocks called the chemical elements.

[5] Jacob Bronowski, The Ascent of Man, BBC documentary series 1975

Period	Discovery	Impact
1874 - Carl von Linde	Invention of the first refrigeration cycle using dimethyl ether and later ammonia.	led to wide spread industrial production of liquefied gases including oxygen, nitrogen, ammonia and propane. Allowed storage of foods and transportation across the globe.
Marie and Pierre Curie	Discovery of unstable, radioactive elements radium and polonium	x-ray imaging, nuclear power, radiotherapy in medicine
1856 - Charles Perkins	Perkins develops first purple dye mauveine, followed by a series of aniline based dyes.	Dye production drives organic chemistry and leads to establishment of some of the world's biggest companies BASF, Agfa and Bayer in Germany
1745 Fiodor Priadunov	First distillation of Petroleum in Baku, used for lighting lamps.	Replacement of whale oil and coal tar. Street lighting became possible
1500-1990	Discovery of painkillers and anaesthetics: opium, ether, chloroform, laughing gas, morphine	revolutionised medicine and made surgery possible
1800 Alessandro Volta	Invented the electrical battery	enabled portable electrical supply
1843 Charles Goodyear	A lifetime of persistence finally leads Goodyear to develop vulcanised rubber.	Led to pneumatic tyres and polymer industry.
1847 James Young	discovers how to distil kerosene from petroleum.	leads to portable and cheap lighting (kerosene lamps). Also leads to naphtha, paraffin, wax and lubricating oils. Gasoline and diesel, solvents, lubricants, asphalt, waxes produced from petroleum, then to synthetic fibres, plastics, paints, detergents, pharmaceuticals, adhesives.
1907 Leo Baekeland	invents first artificial plastic - bakelite	opened up the field of polymer chemistry, revolutionised the manufacture of household goods.
1938 Wallace Carothers (du Pont)	invention of Nylon 66	revolutionised garments and clothing, then extended to moulded parts in furniture, flooring.
1909 Fritz Haber & Carl Bosch	Invention of chemical process to make ammonia, making it possible to produce large amounts of fertiliser.	450 million tonnes prodcued annually. Quadrupled agricultural productivity. Uses 3-5% of world's natural gas annually

Period	Discovery	Impact
1939 Paul Muller (DDT) **1940 W G Templeman (2,4-D herbicide ICI)** **1970 Glyphosate John Franz (Monsanto)**	Discovery of pesticides and herbicides	Major driver for increased food production and productivity of arable land. Yields 4 fold return to farmers. Used with transgenic crops.
1953 - Crick Watson and Franklin	Discovery of the Structure and Mechanism of DNA	Explanation for heredity, diseases and how cells function and life evolves.
1985 Harold Kroto, Richard Smalley, Robert Curl **1991 Sumio Iijima - nanotubes**	Carbon as a new material. Lighter harder and stronger.	Revolutionises energy efficient materials design from bicycles to aircraft.
1983 Kerry Mullis	PCR - enables the rapid scale up of a single strand or small amount of DNA	Revolutionised forensics, genetics testing, transgenic implantation.

In the 21st century, chemistry is expected to contribute to energy efficient LEDs, solar cells, electric vehicle batteries, water desalination technology, biodiagnostics, advanced materials for durable clothing, aerospace, defence, agriculture and health and medicine.

Winds of Change – The Global Megatrends and Threats

Our world is changing in extraordinary ways. For the first time in history, humans now occupy all the easily inhabited regions of this planet. This has created the first true global economy. However, this unique situation brings with it a host of challenges for science and society. The principal question of course is, how can we support an ever increasing population of highly connected citizens, who all aspire to a high degree of material wealth, nutrition and mobility?

There are at least 4 emerging "megatrends" that are going to strongly affect our lives over the coming decades (Table 2). These trends are complex, they interact with each other but their growing importance is undeniable. There is wide agreement globally amongst major consulting companies, business and government advisors, and within the major powerhouses of the global economy, that these trends are real and that research and better science are required to enable adaptation, regardless of which one of these trends in the end becomes the major driver for global change over the next 20 to 30 years.

Table 2: Megatrends, their impacts and rising challenges

Megatrend to 2050	Impact	Rising challenges
Demographic shifts • Population growth • Population age profile shifts • Increased urbanisation • Rise of individuality • Rise of middle class in developing countries	9.7 billion people by 2050. ~21% of the population aged over 65 years. 75% of the population living in urban environments. Mega-cities in coastal areas and mega transport corridors 40% of Gen Y living in India and China. Increasing middle class in developing countries.	Increased Greenhouse Gas generation Management of water Waste management. Transport and housing infrastructure and processes Power generation and distribution to meet demand for

	Increasing demand for consumer goods and services. Uncertain labour opportunities for both young and older people. Increasing trend to migration.	heating, cooling, transport and technology Access to Education Epidemics and human health. Employment (especially of youth and older people)
Technology as an enabling force • Digitisation • Interconnected technology • Pervasive technology • Convergence of technology	Increasing number of electronic equipment for individual, business use, transport and government use. Collection of big data for analysis and solution development for business, cultural and social benefits. Convergence of competition. "Third economy".	Shortage of rare chemicals used in electronics. Electronic and chemical waste. Faster economic cycles due to faster communication and technology. High power demands to maintain technology functionality Cyber security risks
Economic power shifts • Economic power shift to developing countries • Multipolar world	Economic power shifts to developing countries Trade liberalisation and Free trade agreements. Capital flow to economically powerful countries. Developing countries become consumer countries with an expanding middle class. Innovation powerhouse countries will be increasingly in Asia, India and traditional countries face competition.	Associated shift in political and military power. Potential risks of instability. Equitable distribution of wealth. Potential new economic, political and military "blocks"
Climate change • Resource stress • Declining sustainability	Water scarcity Increased push of agriculture into marginal landscapes. Competition of agriculture and urban development for land. Agriculture for chemical and transport feed-stocks rather than food Food scarcity. More severe weather events with agricultural land and building infrastructure damage and loss	Food shortages Water shortages Scarcity of phosphorus and other elements used for fertilisers. High energy demand for heating and cooling. Equitable access to food and shelter. Financing and rebuilding of flood and storm damaged infrastructure

Other Global Game Changers, Threats and Risks

The global megatrends will determine the strategic positions and actions of most economies but they will also influence industry, law makers and knowledge suppliers in chemistry teaching, research and industry. They will need to consider a number of specific global game changers and risks that together with the megatrends are able to cause substantial shocks to all stakeholders.

In 2014[6] the 10 highest global risks over the next 10 years were identified as follows (Table 3):

[6] Global Risks 2014, WEF 2014 http://www3.weforum.org/docs/WEF_GlobalRisks_Report_2014.pdf

No.	Global Risk
1	Fiscal crises in key economies
2	Structurally high unemployment/underemployment
3	Water crises
4	Severe income disparity
5	Failure of climate change mitigation and adaptation
6	Greater incidence of extreme weather events (e.g. floods, storms, fires)
7	Global governance failure
8	Food crises
9	Failure of a major financial mechanism/institution
10	Profound political and social instability

Source: Global Risks Perception Survey 2013-2014.
Note: From a list of 31 risks, survey respondents were asked to identify the five they are most concerned about.

Table 3: The ten global risks of highest concern in 2014.

Chapter III - The “Grand Challenges” for Chemistry

National Research Priorities provide researchers with directions and areas of strategic importance. They help galvanise the research community and they identify areas where important breakthroughs, major discoveries and technological advances are required. Strategic and applied chemistry allow us to maximise the benefits of existing chemistry knowledge but they do not stimulate new ideas, advances and understanding.

Scientists can advance our knowledge by filling in “obvious” gaps in current bodies of knowledge or by extrapolating from what is known, in order to predict where important new discoveries might be made. Such a strategic approach is often useful when the target and challenges are evident and clearly demarcated. Chemistry continues to provide important solutions in this way - for example, chemically generated fibres such as rayon and nylon continue to become stronger and lighter, while metal alloys for planes and engines become lighter and yield greater fuel efficiency. Drugs and other pharmaceutical formulations become more efficacious and have fewer side effects. National Priorities help to focus activity in these areas.

Adaptive global trends in research direction, infrastructure and Chemistry R&D investment

In response to potential high impact, global megatrends, most countries have set R&D priorities and policies which are designed to mediate the impacts of potential risks to the national economy.

The Australian Government has outlined five National Challenges and several associated Research Priorities for the Australian economy (Table 4)[7].

Table 4: National Challenges and Research Priorities

National Challenges	Associated Research Priorities
Living in a changing environment	• Identify vulnerabilities and boundaries to the adaptability of changing natural and human systems • Manage risk and capture opportunities for sustainable natural and human systems • Enable societal transformation to enhance sustainability and wellbeing
Promoting population health and wellbeing	• Optimise effective delivery of health care and related systems and services • Maximise social and economic participation in society • Improve the health and wellbeing of Aboriginal and Torres Strait Islander people
Managing our food and water assets	• Optimise food and fibre production using our land and marine resources • Develop knowledge of the changing distribution, connectivity, transformation and sustainable use of water in the Australian landscape • Maximise the effectiveness of the production value chain from primary to processed food

[7] http://www.innovation.gov.au/StrategicResearchPriorities

Securing Australia's place in a changing World	• Improve cybersecurity for all Australians • Manage the flow of goods, information, money and people across our national and international boundaries • Understand political, cultural, economic and technological change, particularly in our region
Lifting productivity and economic Growth	• Identify the means by which Australia can lift productivity and economic growth • Maximise Australia's competitive advantage in critical sectors • Deliver skills for the new economy

However, both the national challenges and the research priorities are broad and do not provide clear directives on specific goals the government wishes to achieve, for example, creating a decarbonised world, higher efficiency in agriculture, reduction in drug, pesticide and herbicide resistance, offsetting future water crises or mechanisms for climate change adaptation or mitigation.

Given the breadth of these national priorities, it is not surprising that most Australian chemistry researchers actively work in fields that match the current National Priorities set by the Australian government.

The Chemical industry and the private finance sector have been more specific in focusing their priorities. For example, the call for integrated chemical solutions has been evident for several years in the goals being set by overseas chemistry organisations.

- In their 2009 Roadmap for the chemical sciences, "Chemistry for tomorrow's world" the Royal Society of Chemistry in the UK listed 10 major challenges, most of which focused on increasing recyclability, sustainability and energy efficiency[8].
- The World Economic Forum (WEF) has over the last few years promoted investment in green technologies and infrastructure in many areas where chemical research can play a major role in improving technologies, rendering them more efficient or in developing completely new processes.
- Several recent publications on green infrastructure implementation [9] and on green infrastructure finance have analysed the green investment landscape.[10]

Opportunities for Australian Chemistry research in the 21st Century

Chemistry can underpin numerous niche and strategic export industries by careful value-add and by identifying changing market locations and emerging markets.

[8] http://www.rsc.org/images/Roadmapbrief_tcm18-158989.pdf
[9] http://news.wef.org/wef-releases-green-infrastructure-implementation-special-publication/
[10] http://www3.weforum.org/docs/WEF_ENI_FinancingGreenGrowthResourceConstrainedWorld_Report_2012.pdf

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

Figure 13: The top ten most important technical challenges for Chemistry in the next decade
(From Appendix 14. Note: Respondents were asked for the top three most important challenges.)

Based on this survey, almost all the challenges nominated by researchers focus on complex chemistry issues and the interactions of chemicals in complex environments. The challenge for chemists is perceived to be one of integrating chemistry to help provide long term solutions - solutions to health, energy and the environment.

While the 19th and 20th centuries focussed on single molecules and chemicals that revolutionised the world (see Table 1), the emphasis has shifted somewhat to “systems chemistry”. The challenges of the 21st century are to find teams of molecules and chemicals that help provide complex solutions, at reasonable cost, with minimal side effects and which can ultimately be recycled. Systems chemistry represents an enormous value chain. In much the same way that automotive manufacturers are underpinned and in turn support a diverse array of component manufacturers, the Australian chemical industry can increase the value of exports by being part of “chemical solutions”.

Challenges for the 21st Century

Strategic research is possible once technological goals and aspirations are identified, for example through focussed national priorities. However, the biggest scientific breakthroughs occur through undirected, blue-sky research. These breakthroughs and advances in our understanding of nature and the world around us advance humanity as a whole. By publishing the results from basic chemical research in open literature, scientific researchers can inspire other people such as entrepreneurs, inventors, and engineers to come up with ways to apply the new knowledge to existing problems.

Many very fundamental scientific questions need to be answered and in most cases there is no obvious way forward except to carry out systematic experimentation.

Many discoveries and advances are serendipitous and evolve from experimentation in unpredictable ways. This does not imply that chemical experimentation is random - instead it is guided by the results of previous investigation and inspired by the ideas of researchers. Grand scientific challenges exist because of the complexity of the problems or because we simply do not understand the chemical phenomena as yet. Funding basic chemistry research is the only pathway to breakthroughs in many cases. The following section outlines key areas where Australian chemistry researchers probe the very edge of our understanding or seek fundamental breakthroughs that will later advance the Australian way of life.

The Chemical Origins of Life

The greatest of all scientific questions is how molecular systems evolved to enable life to emerge on the primordial earth. Chemists in many countries, including Australia, are addressing many questions around this topic such as:

- How do complex organisms arise from simpler chemical structures? Is the formation of complex structures and life itself always spontaneous?
- How does photosynthesis work - the single most important chemical reaction on earth?
- How do chemicals regulate the temperature and climate of our planet?

Answers to these questions may help us to find solutions for alternative chemical energy sources to fossil fuels and solutions towards artificial regulation of our climate.

Biological Chemistry

Ever since the greatest scientific discovery of the 20th century – the chemistry of DNA – chemists have been making remarkable discoveries about how our bodies work. But there are still many basic discoveries and questions to be answered before we have even a basic understanding of the intricacies of cell metabolism.

- How do proteins fold?
- What is the role of free radicals in the ageing process?
- How does chemistry govern cell differentiation and mitosis?
- How can we do 3D crystallography in real time?
- How can we detect and identify single molecules including toxins, viruses and proteins in complex structures and substrates?
- How can we build a DNA computer? How can we read the base pairs on a single DNA strand?

These complex questions will undoubtedly improve the health and well-being of Australians, but we cannot predict how easily the answers will be found.

Nuclear Chemistry

The nucleosynthesis of the elements inside stellar furnaces produces the molecules of the Universe. But we know little about other stable building blocks, such as for example, the chemistry of muonium. Other questions include:

- What are the ultimate limits of the periodic Table? Is element 137 the uppermost stable element? Current models suggest no element can exist above this atomic number.
- What Chemistry can we do with other atomic particles? There are over 100 sub-atomic particles. But all the elements we see are comprised of just three – electrons, protons and neutrons. Is there chemistry beyond these three particles and what would the applications of this type of Chemistry be?

Chemistry of the Earth, the Environment and Beyond

Although we know how molecules behave in the laboratory under standard conditions, their behaviour at high pressure or high up in the atmosphere is less well understood. The transport of chemicals across the globe is a complex process. The chemistry of the entire biosphere must be understood before we can confidently build a sustainable global community. Some of the questions that need to be answered, include:

- Using radioisotopes, how can we precisely determine the age of the earth? The solar system? Life on this planet?
- How do raindrops nucleate in the atmosphere? Can we control the weather through chemistry?
- Can we offset greenhouse warming through smart chemistry?
- Do we understand the chemistry of the ozone layer?
- How does chemistry vary on the other planets? Can we mine the outer planets? Can we predict the planets and moons likely to have useful ores?
- Chemistry within the Earth's crust occurs under unimaginable conditions at high temperatures and pressures. Can we predict the composition of the earth's mantle and core? Can we predict the existence of important minerals? How does geological chemistry impact us through volcanism and earthquakes?

Discoveries in this field may allow us in the future to manipulate the earth's climate, the chemistry of greenhouse gases in the atmosphere and understand the historic distribution and movement of elements during the earth's history. Alternative sources of rare elements from other stellar bodies might be an alternative to invention of new recovery and recycling chemistry methods. Answers to these questions will help us in the long term to understand our changing environment.

Chemistry for Energy

Richard Smalley, Nobel Prize co-winner in 2003 for the discovery of C60, nominated energy as the greatest modern challenge for science. There are many potential approaches to finding sustainable energy. Key questions in this area include:

- How can we create room temperature superconductors?
- How can we find replacements for indium (used in computer displays TVs)?
- How can we lower the cost of ammonia and methanol through the discovery of new catalysts?
- How can we design and synthesize room temperature superconducting materials?
- How can we harness solar energy as a means of sustainable energy production (artificial photosynthesis)?
- How can we develop better thermoelectric materials for converting heat into electrical energy?
- Can and should we build molecular machines? Converting light energy directly into mechanical work is in principle the most efficient way to use energy.

Discoveries in this area would address many of the challenges in agricultural productivity, energy production and the need for new materials to adapt to the many challenges brought about by climate change and the need for continued technology innovation. Energy research remains essential for Australia, since the cost and availability of energy is central to productivity and economic growth. However, only sustainable or renewable energy with minimal side products such as radioactive waste, greenhouse gases or carcinogenic particulates will provide long term solutions.

Green Sustainable Chemistry

New opportunities will arise from more sophisticated chemical synthesis that can help with waste minimization, energy efficiency, zero waste and recyclability. Questions in this application field include:

- Recycling: The New Plastic Economy – How can we make all plastics biodegradable or recyclable?
- How can we create sustainable battery technology for the 1000 km electric car and for industrial applications?
- Is there a better (cheaper) way to purify water than desalination?
- Can we make fuel cells that operate at 95% efficiency?
- How can we develop new environmentally benign pesticides and herbicides to maintain current rates of crop production?
- How can we manage drug, pesticide and herbicide resistance in a more clever way that predicts and utilises the target organisms' response capability.
- How can we make molecular manufacturing feasible? (building structures atom by atom)

Sustainability is tied to chemistry. We can only improve sustainability at all levels from social to geological by understanding the chemical cycles of products and molecules from cradle to grave. These are complex matters and the impact of chemical waste on the Australian environment may well be different to the impact in other parts of the world. It is essential that Australian governments support research into the costs and benefits of products in the Australian context.

Chapter IV – Chemistry in Australia

The Australian Industry

The Australian chemical industry is an AUD38.6 billion dollar enterprise employing 60,000 people across Australia and contributing 15% of total Australian manufacturing. The Australian chemical industry directly contributes over $11.3 billion dollars to Australian GDP each year.

This is small by global standards, despite the abundance of natural resources we enjoy. Although Germany has just 4 times the population of Australia, it is home to at least 3 of the top 10 chemical companies in the world (BASF, Linde and Bayer[11]). The gross revenue of BASF in 2014 exceeded that of the entire Australian chemical industry while the turnover of the company DuPont de Nemours with USD 35.3 billion sales and 63,000 employees worldwide[12] is similar in size and turnover to the entire Australian Chemical industry.

Large Australian owned companies include household names such as Dulux, Boral, BlueScope Steel, SPC, BHP Billiton, Rio Tinto, and CSR. Only 2 companies are in the top 110 chemical companies in the world. These are Orica at 69 and Incitec Pivot (Australia) at 103[13].

Nevertheless, the Australian Chemical and Plastics Industry is the second largest manufacturing sector in Australia. It is essential in 109 of Australia's 111 industries[14]. The majority of outputs from the chemicals and plastics industry are used as inputs into: manufacturing (valued at $19,346 million), construction ($6,639 million), agriculture ($2,916 million), mining ($1,724 million) and health care and social assistance ($1,352 million)[15]. Manufacturing is, therefore, the biggest user of inputs from the chemicals and plastics industry, using 39 percent of chemicals[16] [17].

The Australian Innovation Landscape

The overall annual trade balance of Australia's Chemical industry has been declining for over a decade[18]. Consequently, the development of new chemical products and business opportunities has also been declining and market analysts state that "… unless a stronger emphasis is placed on research and development, then Australia will lose any footing in the international market. This is not only due to the number of companies moving processing and research off-shore, but also due to the decreasing number of university students enrolled in chemistry"[19].

Australia has a considerable number of large, foreign-owned, chemical companies. These subsidiaries function primarily as sale points or are involved only in core manufacturing. The industry is heavily weighted towards low-end, primary chemicals that capitalise on the availability

[11] ICIS top 100 Chemical Companies 2014 http://img.en25.com/Web/ICIS/%7B182b8502-fa2d-4cd6-9ad7-133a3db38e16%7D_FC0432_CHEM_201409.pdf
[12] http://www.forbes.com/companies/ei-du-pont-de-nemours/
[13] http://www.chemweek.com/lab/Billion-Dollar-Club-2012-BASF-takes-top-ranking-for-seventh-straight-year_55646.html
[14] The-importance-of-science-to-the-economy.pdf
[15] PACIA_strategic_directions_WEB.pdf
[16] ABS 2011: Australian National Accounts: Input-Output Tables, 2007-08 Final Catalogue Number 5209.0.55.001. Canberra: Australian Bureau of Statistics
[17] http://www.pacia.org.au/aboutus/business_of_chemistry
[18] http://www.pacia.org.au/docs_mgr/PACIA_Report1_ElementsInEverything.pdf
[19] "Analyzing the Australian Chemical Industry" http://www.researchandmarkets.com/ report April 2014.

of natural resources, such as broad acre agricultural chemicals. These primary chemicals often end up as large volume, low margin feedstocks for the construction, mining and agricultural industries. The final step of developing niche, high-value products has been de-emphasized since the mid-1970s.

As a result, Australia is poorly represented in the global system for production of the final, advanced manufactured chemicals utilised in advanced technologies, exemplified by the list of key consumer markets. This cannot be attributed to Australia's small population. Of the top 110 chemical companies in the world, at least 10 are from countries with populations smaller than Australia's. (Israel Chemicals – Israel; DSM, Shell, Akzo-Nobel, Lyondell-Basell – Netherlands; Syngenta, Clariant, Givaudan, Ineos – Switzerland; Solvay - Belgium)[20]. The Scandinavian countries and Switzerland all have highly efficient, technology-based economies with advanced innovation systems and efficient translation mechanisms. They focus on niche applications and ensure they offer unique products that cannot be duplicated easily elsewhere.

The Swiss approach to innovation through support of industry/research sector R&D with a strong focus on SMEs through their CTI schemes is one model that has allowed Switzerland to consistently rank at or near the top of various OECD ranking tables and be extremely competitive globally, despite a very strong currency. Similar models are established in Germany[21].

This poor representation in high-end, speciality chemical development and manufacture is also reflected in Australia's extremely poor OECD ranking for interactions between the research sector and industry, where it ranks bottom at no. 33 out of 33 countries. Of the 33 OECD countries assessed, the mean "interaction level" is around 30%. That is, 30% of all firms in these countries collaborate with Universities, whereas in Australia it is less than 4%. This is less than in Mexico, Chile and Turkey! The gap is strongest for larger firms, but Australia ranks last in collaboration for both SMEs and large companies[22].

A key metric for innovation potential is the patenting rate and the strength of the capability to translate IP quickly and efficiently into products, processes and services that the world wants.

Patenting rates in Australia are high. According to the World International Patent Office (WIPO), the chemistry relevant sections of: medical technology (7.8%), biotechnology (5.1%) and pharmaceuticals (6.5%) account for nearly 20% of Australian patents. Overall, Australia produces sufficient new IP, ideas and potential innovations to be more competitive. However, translation of IP into products is lacking.

According to the World International Patent Office (WIPO), the Australian entities with the largest number of patent applications in 2013 were CSIRO, Cochlear, followed by the Universities of Monash, Queensland and Sydney. Conversely, the top 10 entities submitting patent applications in the US were all industry companies. Fine organic chemicals (4.1%) also constituted a significant fraction of patents in the US. By comparison, Australia depends far too strongly on public sector research for IP creation and R&D outcomes.

[20] http://www.chemweek.com/lab/Billion-Dollar-Club-2012-BASF-takes-top-ranking-for-seventh-straight-year_55646.html
21 Steinbeis Stiftung. http://www.steinbeis.de/de/
[22] OECD SCIENCE, TECHNOLOGY AND INDUSTRY SCOREBOARD 2013 page 127.

The high focus on public research sector IP, combined with low translation and low R&D efficiencies together constitute a major weakness impacting negatively on potential industry productivity, growth and profitability,

- There is low awareness of the potential of patentable innovations to drive industry competitiveness in a global, carbon-constrained environment.
- Australian chemical companies have a poor understanding of the capacities and capabilities of Australian research providers.
- Small industry companies are disadvantaged in their interactions with R&D providers.
- The declining viability of Australian chemical companies makes chemistry an unattractive career choice.
- Traditional university education models limit the value of graduates and research professionals to industry employers. Graduates are not deemed to be able to contribute to innovation and manufacturing capability.
- There is poor awareness of the low efficiency of current industry, especially SMEs.

The Chemistry "Value Chain" in Australia

Chemistry is the largest value-adding-chain in Australia and it should not be seen simply as the "production chain of chemicals". The true value adding process is more complex and there are a number of distinct stakeholder communities that contribute to value creation from chemistry, from education and discovery through to manufacturing and the end users. This is the chemistry "value chain".

At each stage of the chemistry value-adding chain, from education and discovery through to manufacturing and the end users, the value increases in different ways (Figure 14).

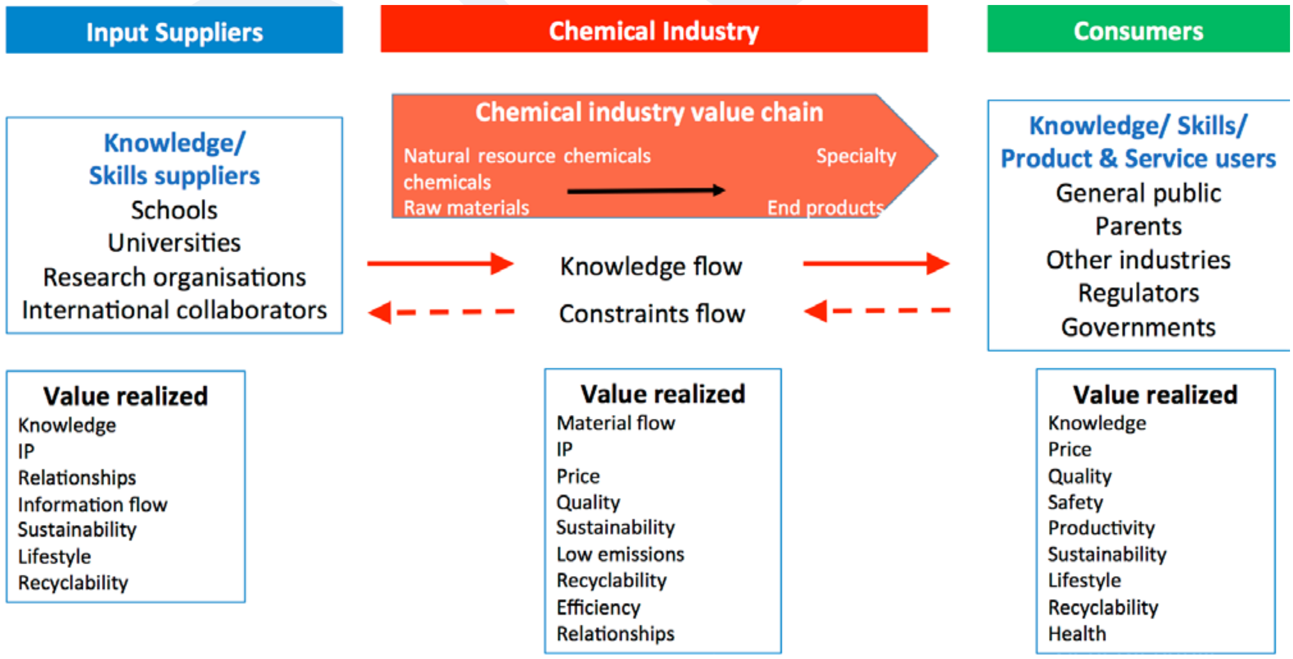

Figure 14: The chemistry sector adds value to the Australian economy through a flow of products, knowledge and IP.

However, there are a number of issues with the chemistry value chain, as summarised:

- Contributors to the chemistry value chain currently operate very much in isolation from one other.
- There is poor understanding and appreciation of the value of contributions from other stakeholders and limited recognition of the way performance in one sector of the value chain impacts performance in another sector.
- Government is a fundamental, essential link in the value chain but it appears to be unaware of its importance and role in ensuring the productivity of each sector and the value chain as a whole.
- Government is seen as having a focus on short-term cost and red-tape reduction, rather than having a long-term, proactive view of the overall operating environment across the entire value chain.
- Resourcing for translation of research outcomes into products, processes and services is inadequate and of insufficient scale.
- Stakeholders attribute poor policy development and lack of value chain thinking to the low science literacy of both policymakers and the general public. Both groups were considered to be suspicious of anything associated with the word “chemical”.

Key Stakeholders in the Value Chain

There are more than 60,000 practising chemists in Australia. They include employees in the chemical, plastics, polymers and pharmaceutical industries and academics, students and researchers in the tertiary sector, as well as professional R&D providers such as CSIRO, the EPA, DSTO and ANSTO. It also includes high school teachers, primary school science educators, and key government departments and policy makers.

The stakeholder analysis for this decadal plan included chemists contributing across the value chain:

- School sector – teachers and students.
- 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.
- 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.

(i) The Higher Education Sector

Australia’s 25 tertiary educators in the field of Chemistry must be able to deliver core knowledge and be able to specialise in key areas of regional strength, focussing for example on the needs of local industry. They need to quickly adopt new chemistry associated with important emerging technologies and build the capabilities to educate students in these technologies more efficiently.

In addition to core chemistry expertise, graduates need more transferable skills and more innovation skills. Industries expect higher education institutions to provide them with “Skilled and productive talent” and this education sector must create graduates not only conversant with the latest cutting edge research fields but also able to fill the ongoing skills shortages of current commercial organisations.

Natural and physical sciences, which include chemistry, have experienced steady growth over the decade to 2010 and consistently represent approximately 12% of the total student load in the higher education sector. The overall student load in chemistry has increased from around 7,600 to just over 10,000 students, with about half of the graduates being women. However, as a proportion of all natural and physical sciences, the proportion of those pursuing Chemistry has declined.

The characteristics of the Chemical Sciences student load have also changed over the decade from 2002 to 2012, with an erosion of the basic Bachelor’s degree at both ends of the graph in favour of postgraduate degrees at one end while “other undergraduate, enabling and non-award courses” have grown in importance.

Employment prospects for Australian Chemistry graduates remain excellent, with 97% of PhDs and 86% of BSc graduates finding employment within 3 months of completing their degrees.

In 2015, it is expected that 80% of science graduates will enter the workforce with a BSc or MSc degree. Only 20% will pursue a PhD in Chemistry and, of those, only 80% will typically complete.

Of the science graduates in 2012, 69% of Bachelor of Science chemistry graduates were working in scientific, technical or engineering roles and 77% of them found an employer with more than 100 employees[23] (Table 5)

Number of employees	2 – 19 Small organisation	20 – 99 Medium organisation	100 or more Large organisation	Total %	Total number
Proportion	8.2	14.4	77.3	100	97

Table 5: Size of full-time employer, Bachelor degree graduates, by field of education, 2013 (%)

The future of Chemistry is determined by our ability to secure satisfying jobs for the vast majority of chemistry graduates, and the vast majority are not pursuing research but aim to apply their knowledge of chemistry in industry or in other sectors of the economy.

The main challenge is to maintain sufficient chemistry expertise in the higher education sector to supply the many chemistry-dependent industries and employers with good quality graduates. Dwindling department staff numbers threaten to reduce the ability of chemistry departments to teach at the levels necessary for industry.

[23] Graduate Destination Report 2013. Graduate Careers Australia 2013

In his analysis of "Staffing university science in the 21st century", Dobson draws the following conclusions on the natural and physical sciences[24]:

> *"Based on full-time & fractional full-time staff, it could not be considered good news to find out that there was a decline in the teaching staff in all of the enabling sciences, despite the increase in the number of students that have to be taught.*
>
> *For example, for the chemical sciences, the number of experienced teaching staff declined by 4% despite student numbers increasing by 39%."*

The last decade of university expansion has seen almost 400 FTE more women, and an absolute decline in the number of men (-47 FTE) among teachers in the natural & physical sciences. Much of the expansion in teaching has been taken up by women, but that expansion is due to an increase in the number of limited term positions, and consequently, it is inevitable that the women appointed are more likely to be in limited term positions.

In 2025, the students who will be entering Year 12 are just 6 years old today. This is precisely the age at which many children's curiosity leads them into chemistry and other sciences. Yet our primary school teachers are seldom scientifically trained[25].

The number of students electing to do STEM subjects at school including chemistry is declining. These subjects are perceived as "hard", rather than "challenging"; current entry into University is biased towards easier courses. There are no mandatory, minimum entry requirements for Chemistry course entrants at universities. Each university has its own entry requirements (e.g. cut-off score). Almost all Universities offer remedial or catch-up courses for students, who neglected to do high school chemistry. This, in turn, means a large knowledge differential across the entry level cohort, ranging from students with no Chemistry knowledge to those who have completed an accelerated science course, with an excellent knowledge of basic chemistry. Yet, all of these students expect to start and complete a Bachelors degree in Chemistry.

There is a wide disparity in the quality of Chemistry courses, and the emergence of second and third tier Chemistry higher education in Australia. While in many countries such as Germany, the US, Japan and China, there are numerous high-quality regional Universities, in Australia, regional Universities have struggled to compete for resources, quality staff and students.

There is also an issue with the lack of a commonly agreed, minimum standard curriculum for a Bachelor of Science.

Furthermore, due to the large differential in quality of graduates from various universities there are specific gaps that universities currently do not fill satisfactorily. Thus, graduates do not always have the skills that industry and government employers need.

Similarly, there is no uniform curriculum available for Primary and lower High School teaching professionals to lift the standards of basic chemistry teaching in schools. (Obviously, at these levels, schoolchildren are doing "general science").

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[24] Australian Council of Deans of Science 2014: Ian Dobson: Staffing University Science in the 21st Century

[25] STEM_AustraliasFuture_Sept2014.pdf

(ii) The Academic research sector

There are a total of 25 Universities that currently offer a BSc (chem.) degree (see Appendix 4) and most of these also support active research programs. The discipline employs almost 1,300 scientists, who are the 'engine room' of the research activity in Chemistry in this country (Figure 20). According to the ARC ERA 2012 National Report,[26] most of the research teams creating research outputs were at or above world standard. 90% or more of the research outputs were journal articles.

Although patent activity is high, the overall research commercialisation income is just 1% of the total research income of the discipline. This is again an indication of the very low level of interaction between academic research institutions and industry and of the low translation efficiency of research outcomes into commercial outcomes.

The major funding agency for the academic research sector is the Australian Research Council (ARC) and ARC Discovery grants are the main source of funding for young, early- and mid-career researchers.

The main concern of the academic sector is the almost complete reliance on ARC funding for research. This lack of diversity is in strong contrast to all other technologically strong economies, which typically have multiple funding sources (although many of these have a focus on strategic and applied research to help the transition to commercialisation).

A second concern is the increasingly poor outlook for a long-term career in academia. The challenge is clear from the basic statistics. In other technologically advanced nations, 70% of PhD graduates enter industry while 30% remain in academia. In Australia, the dearth of industry investment in R&D has resulted in 70% of graduates being employed in academia and just 30% in industry.

(iii) The Australian Government research sector

The Australian Chemistry research sector is diverse and comprises a wide range of organisations that provide key scientific services and research outputs to Government and the community. Significant institutions include CSIRO with their various flagships, DSTO, ANSTO and researchers in other government departments such as EPA, TGA, FSANZ, IPA, Dept of Health, DAFF, BOM, SafeWorkAustralia and others. There is also collaboration of the sector with university research laboratories and participation in both Centres of Excellence and Cooperative Research Centres (CRCs).

It is extremely difficult to obtain figures on the number of chemistry professionals in the government research sector as research personnel are usually employed in an organisational role and not specifically as a "chemist" or "chemistry professional". However, according to our survey approximately three quarters of researchers are male, tenured and under 50 years old and approximately 70% are early to mid-career researchers (Appendix 14).

The fields of work that are covered are broad with the largest single field being "organic chemistry", followed by "macromolecular and materials chemistry". Typically, these staff have high qualifications and extensive and varied work experience, with 48 % having worked overseas, 45% having worked in industry or business and 51% having worked in an academic institution.

[26] http://www.arc.gov.au/pdf/era12/report_2012/ARC_ERA12_Section2_03.pdf

The most common reason for leaving industry was that government research positions were seen as a better opportunity and the second most common reason was restructuring of the industry company with loss of employment. Personal/family reasons ranked third.

The most common reason for leaving academia for a government agency research position was that the government job was seen as the better opportunity, most likely due to the prospects of a tenured position. The second most common reason was that the contract at the respective academic organisation had expired. Personal and family reasons ranked third on the list.

A key concern expressed by industry was the poor speed of delivery by the government sector and the excessive red tape associated with working with government agencies.

Members of the academic sector consistently noted that there is no clear delineation between the work that goes on in government laboratories and work in universities. Many academics believed there is a substantial amount of fundamental research funded by CSIRO for example, that should be carried out in academic institutions. Conversely, some of the smaller universities are doing applied research that could be better carried out by CSIRO.

Another identified issue is that SMEs were viewed as high-risk customers by the government research sector. Compounding this, there was a clear view by SMEs that research provided by government laboratories was unaffordable for them.

(iv) National large research facilities

Australian chemistry is strongly supported by NCRIS funded infrastructure, ranging from high-resolution electron microscopes and nanofabrication centres (ANFF, MCN), through to the Australian synchrotron and neutron beam facilities at ANSTO.

While chemistry is generally considered “small-scale“-science, increasingly chemists rely on access to National Facilities to answer fundamental questions about material composition or structure. Australian chemists account for 30% of users at the Australian Synchrotron and 30% at the Australian Nuclear Science and Technology Organisation (ANSTO).

There is strong support for the proposed second Guide Hall for OPAL at ANSTO. Installation of this core infrastructure would open up the possibility of adding a further 15 dedicated scientific instruments/beamlines in future years, and Australian chemists strongly supported the decision to build the Australian Synchrotron (AS).

(v) Connecting Industry, Academia and research providers

According to the OECD, Australia has the worst performance of any developed country in terms of the connectivity and collaboration between its academic and industry sectors[27].

The overwhelming sentiment was that the relationships between industry and the higher education and research sectors are not functioning well. The inflexibility of the current Higher Education and R&D sectors was seen as a major barrier to a constructive relationship. This was especially true for

[27] http://www.globalinnovationindex.org/userfiles/file/reportpdf/GII-2014-v5.pdf

the way University administration arms dealt with industry. However, constructive ideas for improving the situation that could be implemented quickly, were not forthcoming.

The lack of an overarching government policy to facilitate and drive interactions between academia and industry and the overall perception of research sector inflexibility in dealing with industrial companies and their fixation on existing funding mechanisms did not make it easy to establish close and lasting industry relationships.

There was consensus that the role of CSIRO as a provider of research to Australian industry (especially SMEs), was not understood by either industry itself, nor by university-based research providers, and that the needs of industry were more at the topical level and required immediate solutions, whereas the research sector was used to solving problems in a five to ten-year timeframe.

(vi) The school education sector – Teaching what Matters

International benchmarking of OECD school educational levels are regularly carried out through the TIMSS and PISA rankings. TIMSS focusses on Year 4 and 8 (roughly ages 8 and 12) while PISA assesses students at age 15. TIMMS assesses students across 3 domains covering life sciences, physical sciences and earth sciences.

In 2011, the last year for which full data are available, Australia's TIMSS score was 516, and, although above the OECD average, this was significantly below 18 other OECD countries. Of the Year 4 students at age 8 or 9, 29% of Australian students did not reach the international Intermediate benchmark.[28]. This means that even at a young age, almost a third of Australian children already have a below-average knowledge of science subjects.

According to the TIMMS 2011 data, only 43 % of students were being taught science by teachers who stated that they were very confident teaching science. As well, just 51% of students had teachers who classed themselves as very well prepared to teach science, and this declined to under 50 % in the areas of physical science and Earth science.

The TIMMS and PISA results suggest that to improve chemistry at the school level, the focus needs to be less on technological innovation and more on improving the number and quality of the chemistry teachers. It is also important to enable practical study in a class room environment that is conducive to learning.

Improving staff-student ratios, providing clear-cut career opportunities for staff and learning chemistry (and science in general) as early as possible will all lead to significant improvements in STEM outcomes, including chemistry.

(vii) School education sector stakeholder consultation - Chemistry starts at six

Curiosity about the world around children begins in children at the age of 5 or 6.

The primary school children interviewed were very excited and curious about science and any chemistry experiment at school, but by the age of six, many had already formed a negative opinion about what the word "chemical" means.

[28] http://www.acer.edu.au/files/TIMSS-PIRLS_Monitoring-Australian-Year-4-Student-Achievement.pdf

Teachers play by far the biggest role in the development of students' attitudes and learning outcomes in their secondary schooling. Revitalising chemistry teaching is essential to the future of chemistry in Australia. But the quality of the training being offered to high school chemistry (science) teachers is lagging dangerously.

A survey of chemistry teachers (Appendix 13) highlighted which challenges were perceived to be the most severe in the current environment (Table 6)

Lack of interest of students	35.9 %
Not enough access to professional development	28.9 %
Not enough Chemistry teachers to talk to	24.1 %
Poor quality of Chemistry facilities	19.3 %
Class sizes too large	15.7 %

Table 6. The top five challenges for Chemistry teachers

(viii) The general public and the public image of chemistry

Australia generally has a very low percentage of citizens with a background in science or technology (STEM). This has led to an alarmingly low percentage of politicians with scientific training. Consequently, our leaders often do not have the ability to understand the implications of technical innovation. Conversely, in China, 8 out of 9 of the top government officials have scientific backgrounds[29].

Despite the contribution of chemistry to global civilisation, the word "chemical" continues to conjure up negative views within the community. There is a need to educate the public away from contradictory statements such as "chemical free food" and to recognise the essential contribution molecular science makes. This is likely to be a generational switch that begins with primary and secondary school teachers. In the shorter term, Australian chemists need to make a more concerted attempt to present chemistry in a positive light in the media.

[29] President Hu Jintao was trained as a hydraulic engineer and Premier Wen Jiabao as a geomechanical engineer. In Singapore, the president is Tony Tan whose degree is in applied mathematics, while the Prime Minister Lee Hsien Loong also has a degree in mathematics. In Germany, Angela Merkel is well known as a physical chemist, as was Margaret Thatcher in the UK. In many European countries, at least 10% of MPs had a scientific or technical background in the 1980s and that number is rising.
Source: ABERBACH, J. D.; Putnam, R. D.; Rockman, B. A., *Bureaucrats and Politicians in Western Democracies*. Harvard University Press: Harvard, MA., 1981.. In the last German parliament, 8 of 26 cabinet ministers were women, while 10 of the inner 16 cabinet had PhDs. Not all of these were chemistry trained, but it is evident that other Parliamentary systems do value people with scientific training.

Chapter V – The Key Requirements for the Chemistry Discipline

Consultation and analysis revealed a number of issues and requirements from key stakeholders across the chemistry value chain. For more details see Appendix 9. The stakeholder requirements here are consistent with a variety of enquiries into the sector over the last decade.[30] [31]

Industry Value Chain Requirements

- All segments of the Australian chemistry community need to develop a unified and collaborative approach for overcoming the causes and impacts of "chemistry illiteracy" and its poor image with the public. All segments need to take on the responsibility for the way chemistry is portrayed in the media and to work on ways to improve its public image.
- Australia needs more science-literate leaders, policymakers and advisors in Government, who can better understand technology-driven change in industry and society.
- The science literacy of the Australian general public needs to be improved so that Australia can have better informed public debate on global issues that require chemistry for effective solutions.
- Australia needs to be pro-active in adopting successful models of innovation policies, strategies and schemes from countries that are leading the innovation rankings.
- Chemistry research translation mechanisms need to be developed that are viable and advantageous for all participants in an environment of limited industry profitability and limited government support. This applies especially to access to translational opportunities for proof-of-concept work through to large-scale chemical industry development.

Industry Requirements

- New, affordable and efficient R&D collaboration mechanisms are required, that can foster links between industry and research providers in Australia, in a cash-poor environment.
- 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.
- Chemistry research translation mechanisms need to be developed that are viable and advantageous for all participants, in an environment of limited industry profitability and limited government support.
- There need to be better, more flexible models for cost recovery (by both industry companies and R&D providers) to balance the up-front costs of R&D in new chemical product development. New Zealand has such a model in place.[32] Other established models exist in Switzerland (Appendix 10),

[30] Australian Research Council. *Mapping the Nature and Extent of Business-University Interaction in Australia*. Canberra: Commonwealth of Australia, 2001.

[31] (a) Department of Education, Science; and Training. *Mapping Australian Science & Innovation: Main Report*. Canberra: Commonwealth of Australia, 2003; (b) Department of Education, Science and Training. *Measuring the impact of publicly funded research*. Canberra: Commonwealth of Australia, 2005.

[32] http://taxpolicy.ird.govt.nz/publications/2015-ris-arrdrm-bill/cashing-out-research-and-development-tax-losses

- New higher education models are required that produce chemistry graduates and postgraduates with the skill sets demanded by the industries of the future.
- Government agencies and industry need to develop collaborative rather than adversarial modes of interaction, in order to benefit faster from changing regulatory outcomes.
- There needs to be early engagement with industry for chemistry students in order to build awareness of industry career pathways as an alternative to the traditional academic career model.
- Industry, and in particular SMEs, need to find mechanisms to improve process efficiencies.

Higher Education Requirements

- New higher education models are required for providing chemistry graduates and postgraduates with the skill sets demanded by the industries of the future. This includes more transferable skills such as mathematics and problem solving skills for increased flexibility, as well as more practical industry experience during their studies.
- To be attractive to the more demanding employers of the future, graduates should have cross-disciplinary expertise, in a second science discipline such as maths, biology, engineering, toxicology, physics, or earth science etc.
- Higher education providers must develop distinct programs that cater for different career pathways (academic, industry and teaching) to prevent overcrowding of the academic pathway. The current cookie-cutting pathway is creating cohorts with poor career prospects and also inadequately equipping graduates for industry and teaching careers. Undergraduates should not be automatically pushed towards an academic career. Instead, specific course curricula must be developed for research, industry and teaching focused graduates respectively.
- Universities need to develop a more flexible approach to teaching chemistry, in order to facilitate faster adaptation to the needs of professional pathways, as new chemistry knowledge leads to new technologies and this, in turn, leads to new skill set requirements.
- The higher education sector and the school education sector need to work together to develop new chemistry education models. For example, they need to develop engaging materials that help chemistry teachers to deliver improved educational and chemistry literacy benefits to children of all ages and backgrounds (i.e. from pre-school to year 12).
- As parents of school children have little knowledge about the value of a chemistry degree, the higher education sector needs to work together with industry and the high school sector to provide suitable information to teachers and parents of middle school children on the diverse job opportunities and career pathways enabled by a chemistry degree.
- The higher education sector also needs to address the issues created by the highly variable chemistry knowledge of students entering tertiary courses in chemistry. In particular, minimum national standards are needed together with clear recognition of the important role chemistry plays in many other degrees (e.g. engineering, medicine).

Academic Research Requirements

- 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.

- 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. This also requires that new metrics for chemistry research efficiency and effectiveness be developed that provide a more balanced picture of each research provider's overall level of competence, rather than just publication based metrics.
- Research data from Australian research providers (e.g. Universities, CSIRO) need to be regularly analysed in a systematic manner to identify potential technologies that could be translated into new products and processes with appropriate support.' For example, lists of recent provisional patents lodged could be circulated to industry and other Universities on a quarterly basis.
- To improve research efficiency and effectiveness, the Australian research sector has to develop increased skills, strategies and better mechanisms for longer term planning of their research, that are not solely reactive to the government policies of the day.
- Australian research institutions and especially the academic research sector need to abandon their focus on safe, run-of-the-mill chemistry research projects in favour of more high risk, strategic work that can become the source of future innovation. The prerequisite for this is a widening of the range of funding opportunities that are available for different purposes (fundamental, strategic, applied).
- Solutions must be developed for the problem of getting a higher number of start-ups off the ground in the chemistry space.
- More balanced reward and promotion mechanisms in research organisations need to be developed that do not disadvantage commercial activity, industrial collaboration and time spent on the creation of patentable IP.

Government Research Requirements

- New and better metrics for chemistry research efficiency and effectiveness need to be developed for the government research sector, in order to provide a better view of the research provider's level of excellence in the international and commercial contexts.
- Research sector research outputs need to be regularly analysed in a systematic manner to identify potential technologies faster that could be translated into new products and processes with appropriate support.
- There needs to be better delineation or demarcation of the remit and strategic directions of government research organisations from those of the academic research sector to avoid research duplication and unnecessary competition. This may help better define the "sense of purpose" that concerns workers across the sectors.
- There is duplication of services, unnecessary delineation of services (e.g. many of the monitoring and registration focused agencies), also negatively impacting on research productivity.
- The funding mechanisms for research funding to the government research and academic research sector is inefficient.

Large Research Infrastructure Requirements

- The major requirement for the sector is ongoing maintenance of the current, large research infrastructure items, and pathways for continuous upgrading to maintain facilities at a world-class level. This was a "top of the list" requirement by the research sector.

- There were strong calls to ensure that there is maintenance of skilled technical support in these large research infrastructure facilities to ensure maximum productivity and research efficiency.

School Education Requirements

- There needs to be at least one science trained teacher in each primary school in Australia.
- The gaps in science literacy of teachers, and especially primary school teachers needs to be addressed as a matter of urgency. It is vital to engage students, to pique their curiosity and to support their interest in science and prevent it from declining prior to entry into high school.
- Chemistry education models and engaging teaching materials need to be developed that are easily accessible by teachers in all Australian schools including regional, remote and disadvantaged schools.
- Professional development mechanisms must be developed for easy access by chemistry (science) teachers in regional and remote locations. It is also important to provide high school staff with opportunities to undertake upskilling and updating of their knowledge of science.
- Engaging information material needs to be developed for parents and middle school students on the types of employment pathways that a solid Chemistry education in high school facilitates. This needs to include up-to-date information about chemistry related job and market developments.

Chemistry Public Image Requirements

- The science literacy of the Australian general public needs to be improved to facilitate informed and better public debate on global issues that require knowledge of chemistry science for effective solutions.
- The entire chemistry community needs to work together to change the way chemistry is portrayed in the media and to improve the public perception of chemistry in the public eye.

These requirements are the key inputs to the development of the strategic directions, goals and recommendations made from the Decadal Plan development process.

Chapter VI: The way forward and strategic direction of the Decadal Plan

This Decadal Plan is basing its strategic direction for the next decade on the requirements and findings of the current state of the Australian Chemistry value chain and the expressed needs of its sectors. The Decadal Plan working group established five strategic goals and a number of strategies to achieve these goals during the next decade.

1. Raise chemistry knowledge and skills in the chemistry value chain.
2. Improve the capabilities of the research sector.
3. Raise the level of research and innovation efficiency and improve the translation of research outcomes.
4. Improve the image of chemistry.
5. Enable implementation of the Decadal Plan.

Strategies that support these goals need to be implementable in a national environment, which also takes into account that facts that every sector of the value chain is constrained by its specific funding and operating limitations and business goals.

It will be necessary to balance the short-term current goals (i.e. improving the productivity of the value chain as a whole and all of its sectors) with future, long–term, strategic goals for becoming competitive and adaptive in a changing operating environment.

This will require cooperation and collective action across the Chemistry value chain as well as sustained strategic funding. The 5 strategic goals are now explored in more detail and some concrete strategies to achieve them proposed.

Strategic goal 1: Raise chemistry knowledge and skills in the chemistry value chain.

Strategy 1.1 - Improve Chemistry education in Primary and High Schools

- Set a minimum pre-requisite of a Bachelor of Science degree with major in chemistry for high school teachers who teach above year 8/9 level chemistry. More highly qualified chemistry teachers will enable better engagement and teaching outcomes for students. If industry placement during the undergraduate degree is one of the features of a chemistry major, then teachers will be able to portray better how chemistry can lead to a valued career for students.
- Set a minimum standard of 1 science trained teacher preferably with a BSc graduate level or at least year 12 chemistry/science qualification for every Primary school to ensure they can portray science and present chemistry principles and knowledge in an appropriate way.
- Enable all high schools to offer modern practical experience in chemistry and develop better models for providing practical chemistry experience to high school children in regional and remote areas and in disadvantaged schools, potentially through networked schools or by improving the logistics of access to chemistry teaching infrastructure.
- Promote chemistry teaching careers at all universities - currently, the career path of a chemistry or science teacher is not sufficiently promoted at universities. Students are generally directed towards an academic or research career first, an industry career second and only into teaching as a last and less desirable option.

- Improve the image of Chemistry teaching as a career - the image of Chemistry teaching as a career is currently poor and there is a need for a targeted and sustained activity in promoting Chemistry as a whole and Chemistry teaching in particular.
- Support ongoing Professional Development of Chemistry teachers and interaction with universities to ensure regular updating of knowledge, teaching techniques and keeping abreast of the field and develop accessible PD opportunities for remote teachers.

Strategy 1.2 - Improve Chemistry education in Academic Institutions (universities)

- Mandate as a minimum entry standard into university undergraduate degrees the successful pass of an agreed Year 12 National Chemistry curriculum and Year 12 Maths.
- Agree a common National Chemistry Curriculum that is accepted by all universities.
- Mandate stricter professional accreditation of chemistry degrees in Australia
- Develop an agreed skills and capabilities profile for Chemistry course and training providers and confirm mechanisms for external quality assessment (e.g. Government/industry) to ensure course curricula and generic attributes (transferable and practical skills, as well as industry placement opportunities) are met to an acceptable standard.

Strategy 1.3: Improve the Chemistry knowledge of policymakers and the general public.

- Mandate that every school leaver has an age-appropriate knowledge of chemistry and/or Science to ensure that no school leaver will be completely chemistry/science illiterate.
- Develop an agreed outreach program for policymakers that enables the chemistry community to provide information on important chemistry related issues that will in turn enable informed discussions, decisions and policy development at all levels of government.

Strategic goal 2: Improve the capabilities of the research sector

Strategy 2.1 Address the National Challenges of the 21st century which fall within the purview of the Chemistry Sciences:

- Develop a set of research priorities that are tri-annually agreed by all sectors of the value chain.

Strategy 2.2 Focus Australian chemists more disruptive chemistry questions and the Grand Challenges of the chemistry discipline.

- Work with funding agencies to ensure that basic, strategic and applied research are all being carried out at the highest level, without conflicting goals and expectations. A clearer understanding at all levels is needed between the aspirations of researchers and the expectations of funding agencies.

Strategy 2.3 Maintain and consistently upgrade large research infrastructure to support Australian research at an internationally competitive level

- Consistently maintain and upgrade existing large infrastructure so that it becomes a focus for Chemistry based research in the Asia-Pacific region.

- Improve productivity of large and medium sized research infrastructure.
- Develop a National Chemistry Research Infrastructure register, that includes important medium sized infrastructure and make it accessible to researchers across the country and industry companies.

Strategy 2.4: Develop more diversified mechanisms for funding and conducting research in the academic research sector

- Develop a broader variety of funding sources for more directed research in order to address the more practical aspects of solving the Grand challenges of chemistry and provide (practical) solutions to the effects of the mega trends, risks and threats. This will need to include novel ways to access funds from parties external to Australia.
- Change the reward and promotion structures in academic research institutions to reward industry engagement, IP creation (patents) and translation. This will require agreed new IP models and translation mechanisms throughout Australia and with all R&D providers, government and the research funding agencies.
- Incentivise stronger R&D investment of industry in academic institution based R&D to enable increased investment by industry and especially the SME sector in Chemistry research.

Strategy 2.5: Streamline and delineate the Government research sector from the academic research sector to enable better fit with value chain needs and faster delivery of unique products.

- Clearly define and delineate between core strategic research in the national interest that should be taxpayer funded, and R&D that is for commercial benefit and should be funded by industry. This delineation should be as clear as possible and supported by appropriate funding arrangements. Fundamental research should focus on areas where scale and teams are needed, which is where Universities generally do poorly.
- Develop mechanisms that can provide better R&D services to international, large national companies and SMEs. These mechanisms should take into consideration current funding constraints of both providers and industry segments.
- Develop models to enable SMEs to develop into more advanced Chemical companies that deliver higher value through innovative products.

Strategic goal 3: Raise the level of research and innovation efficiency and improve the translation of research outcomes

Strategy 3.1: Improve innovation capability of the academic research sector to enable faster and more targeted delivery of research outcomes

- Develop and incentivise better mechanisms for research translation that benefits all parties at the outset. Current mechanisms have drawbacks for both industry (lack of speed and high cost) and the academic sector (limitations on ability to publish, directed research, project management based research process). Better mechanisms are needed to increase the speed with which research outcomes are attained in order to improve research productivity.
- Improve the delivery times of R&D outputs to industry (become faster in delivery and improve interactions with customers and other parts of the Chemistry value chain).

Strategy 3.2: Develop mechanisms and processes for lifting the innovation capability, productivity, competitiveness and adaptability of the Australian Chemical industry

- Develop a pilot scheme (e.g. along the lines of the Swiss CTI model with innovation mentors who are specialized in supporting both Chemical industry technology development and start-up companies). This model would enable the matching of industry company needs with research provider capabilities to address specific needs and deliver high tech or high end competitive results.
- Develop processes and mechanisms for building more formal and long lasting relationships between industry, the higher education sector and research providers. This should focus on demonstrating and realising value for industry and research providers. The process should be largely driven by independent industry participants to ensure focus is on new products or processes and on productivity, effectiveness and results.

Strategy 3.3: Improve the effectiveness and efficiency of interaction and communication throughout the Chemistry value chain

- Improve the interactions and communication between all sectors of the Chemistry value chain. Currently each sector has their own affiliation banner to which they belong (e.g. PACIA for industry, RACI for Chemistry researchers, ATSE and others). A more integrative approach is needed to facilitate communication, interaction and a common response of the Chemistry value chain to issues and threats.
- Develop and agree on a common communication plan for the complete value chain. Currently all sectors have their own plans, developed with very little consultation between sectors and this needs to be improved for delivering long term benefits. The goal is to limit confusion within and outside the value chain and to enable a unified response to issues and problems.

Strategic goal 4: Improve the image of Chemistry

Strategy 4.1: Promote Chemistry to the general public and portrait a positive and realistic image of its value to society

- Develop and fund an agreed media strategy to enable a constant media presence in the major media to provide frequent information about positive Chemistry results and the value of Chemistry in general. In contrast to many other science disciplines, Chemistry is almost absent in many media. For example news about new planets, the successes of space science, biology, medicine and biotechnology are highlighted every week, often several times on multiple media platforms. Chemistry is absent from the spectrum of news items. To address this a structured approach is needed.
- Develop and implement an agreed and nationally coordinated outreach program and ensure that every school in Australia has physical contact at least once a year with a Chemistry scientist or industrial chemical professional. There is currently no national strategy on how to deliver an effective chemistry outreach program to schools. Most Universities work on outreach independently and with little coordination.
- Develop mechanisms for access by individuals of the general public to Chemistry professionals. This could be in form of a “find a chemistry expert” scheme that ensures that anyone can find access to a chemical expert to get answers to Chemistry related questions. This is particularly important for assisting media driven enquiries.

Strategic goal 5: Enable implementation of the Decadal Plan

Strategy 5.1: Set up and fund a Decadal Plan implementation committee that represents and focuses on the interests of all segments of the Chemistry value chain

- Appoint a committee with members from all sectors of the value chain and develop appropriate terms of reference.
- Source funding for the operations of the committee.
- Develop reporting mechanisms, KPIs and milestones, including a mid-term review for the committee.
- Develop a budget for the implementation plan.

Strategy 5.2: Develop a common value chain roadmap and a long-term rolling strategic research and development plan to facilitate its adaptability to global, regional and national threats and opportunities.

This is expected to be part of the remit of the Decadal Plan implementation committee.

Chapter VII - Plan Implementation

The Way Forward

At a glance:

- The strategies outlined in this Decadal Plan are intended to achieve greater cohesion and connectivity across the chemistry sector, and to support each segment of Australia's largest industrial value chain;
- An Implementation Plan will be developed by a Committee drawn from stakeholders in the Chemistry community;
- The work of this Committee must be actively supported by the wider Chemistry community in order to have the appropriate authority to develop and oversee the implementation of the strategies in this Decadal Plan;
- A mid-term review of this Decadal Plan in 2020 will be used to assess progress, analyse outcomes and determine necessary changes.

The Chemistry Decadal Plan is a vision for the future of Chemistry. Based on ideas and contributions from the entire Chemistry community, it aims to guide the development of the discipline over the next ten years. The Plan outlines a number of strategic goals that will significantly improve opportunities for chemistry in Australia in the industrial and academic spheres.

This plan belongs to us, the Australian Chemistry community. It represents our aspirations and ideas, our challenges and opportunities. We must recognise that responsibility for its success lies with us – every person and organisation involved in Chemistry in Australia. We must support it, we must commit to it and we much contribute to its implementation in order to realise the benefit that will flow to everybody involved in the Chemistry value chain.

Implementation of the Decadal Plan will be a challenging endeavour that will require the active support of the entire Chemistry community. That is why we must commit to working together as a community to implement the Plan. We must be able to speak with a united, respected and persuasive voice. It is up to us to persuade policy-makers and other important stakeholders that our ideas represent significant opportunities for Australia and its prosperity.

We must show the community the value of Chemistry in Australia. We must show the community how chemistry underpins significant economic benefits in the manufacturing sector now, and how it provides opportunities for a better life for future generations of Australians. We must share our successes with the community. We must show that Australia differentiates on quality, and is proactive in seeking new areas and markets to develop.

We must work to persuade the Australian community, through business and governments, to maintain the vitality and strength of the Chemistry sector. We must encourage business and government in Australia to be bold in seeking new opportunities for chemistry to further enhance our economic, social and environmental well-being. We must work to ensure that Australian chemistry is world-leading in its areas of strength, and is seen as such. We must make the Australian Chemistry sector the natural home of the highest quality Chemical research, expertise, goods and services.

The next steps

In late 2015 and early 2016, the Chemistry sector will come together to form a group of high-level representatives to translate this Plan into action. The Implementation Committee will be drawn from representatives of industry, education and academia and will take on the task of developing an implementation plan that will identify specific initiatives and opportunities to progress towards our strategic goals.

- Within two months of constitution, the Committee will have developed its enabling framework (terms of reference, meeting schedule, secretariat support arrangements, final composition)
- Within six months of constitution, the Committee will have developed a draft implementation plan
- Within twelve months of constitution, the Committee will have developed a draft set of specific initiatives to operationalise the implementation plan.
- Within eighteen months of constitution, the Committee will have connected proposed initiatives with the necessary leadership, stakeholders and resources to enable their implementation.

The success of the Implementation Committee will depend on active support from the Chemistry community to:

- Directly support the work of the Committee
    - Provide high-quality, constructive input to the Committee’s work
    - Provide time, expertise and resources to the work of the Committee where appropriate and available
    - Actively identify opportunities for the implementation of the Plan in our own networks and workplaces

- Build a critical mass for the Decadal and Implementation Plans:
    - Create awareness about the work of the Committee and the progress of the Plan with our colleagues, managers, stakeholders and professional associates
    - Engage with our peers with our ideas for the Plan
    - Strengthen the voice of Chemistry by taking part in sector-wide initiatives to engage with business, government and the wider community
- Create a cohesive, committed and respected Chemistry community
    - Commit to forging Chemistry relationships outside of routine activities
    - Commit to connecting students and junior colleagues with the Chemistry community, through industry bodies and professional associations
    - Commit to promoting a culture of collaboration throughout the sector
- Assess, evaluate and improve the plan
    - Initiate and contribute to a mid-term review of the progress and strategies of the Decadal Plan and the Implementation Plan in 2020.

By working together as a united community, the Chemistry sector has the opportunity to realise the vision and the objectives set out in its Decadal Plan. If the Implementation Committee has the community behind it, its ability to influence business, government and stakeholders will be greatly magnified. If we can engage the networks and resources of the entire community, then we will be better able to turn ideas into actions. If we can work together to help implement the Plan, then we will discover new opportunities to further strengthen our sector.

Australia must continue to invest in maintaining the vitality and strength of its Chemistry sector. The Decadal Plan offers the tools to the leaders of the Chemistry stakeholder sectors to make this possible.

Considerations and guidelines for a Decadal Plan Implementation Plan

An Implementation Plan is an essential part of a business plan such as this Chemistry Decadal Plan. It should contain a proposed sequence of implementation steps that take into consideration interdependencies between the various steps that need to be implemented, as well as a list of the assumptions made while developing the Plan.

Dependency analysis of the strategic structure of the Decadal Plan

To identify interdependencies between strategies, Dependency Structure Matrix analysis methods[33] were used to:

1. Define those groups of strategies and sub-strategies that were connected via dependencies in a modular form. For this dependency analysis a clustering algorithm was used that aggregated those strategies into clusters that had most interdependencies within the cluster and few outside the cluster.
   This visual arrangement of these clusters allows different groups of people with appropriate skills to be identified, who would be best placed to develop budgets and drive the tasks that need to be accomplished to ensure that the strategies within the cluster are implemented efficiently and effectively.
2. Define the sequence of implementation, by identifying which strategic outputs need to be used as inputs into other strategies.
   The strategies are then sorted, with those having the fewest dependencies being allocated to the beginning of the implementation process, and those that depend on the outcomes from others being pushed back to the end of the implementation process. The required resources, cost and effort for each strategy implementation task are then determined and finally, a schedule is constructed together with an overall implantation budget.
3. Identify those 'blocks' of strategies that may require special consideration because of extensive interdependencies and potential for likely iteration.

Cluster analysis

Cluster analysis showed that there were five implementation clusters or "strategic modules"

1. Establishment of the implementation committee and its working budget, KPIs, TORs, funding, and issues involved with further iteration, i.e. adjustment of the strategic direction after acceptance of the Decadal Plan.
2. Redefining the education of Chemistry, both in the school and the higher education sector. Due to the many interdependencies between both the school sector and the higher education sector, the analysis found that there should be a common implementation module with a working group that spans both sectors.
3. Improving the working relationship and efficiency between industry and the research sector. Part of this implementation module is the development of a common value chain roadmap and R&D plan, incentivisation of research provider interaction with industry and the proposed innovation mentorship scheme. The implementation of this module requires a working group with specialised skill sets, i.e. with expertise in both industry and research in terms of high commercial success and high research success, as well as appropriate industry and government membership.
4. Improving the research efficiency in terms of defining clearer priorities, infrastructure productivity increases and defining a better risk balanced research portfolio.

[33] Eppinger, S.D. and T.R. Browning (2012) Design Structure Matrix Methods and Applications, Cambridge, MA: MIT Press.

5. Development of a media strategy and a Chemistry expert access program. This smaller module requires very specific expertise and highly developed networks cross the Australian chemistry stakeholder community.

The grouping of the strategies within the clusters does not mean that all of them need to be implemented in the sequential order listed above. They can be addressed, or at least started, simultaneously if the necessary expertise can be assembled quickly and funding for operation is made available, initially for developing a budget for implementing each of these modules.

A full implementation plan detailing human resource requirements and operating budgets for addressing the five strategic modules should be created by the Implementation Plan Committee.

Sequencing analysis

The next stage of the analysis involves re-ordering the list of Decadal Plan strategies in order to arrive at an optimized order for implementation.

The order in which strategies should be implemented is probably not surprising. However, a number of tasks are highly interdependent and therefore there is a high chance of unplanned iteration that can potentially lead to failure in the activities that relate to interaction between research providers and industry and the type of research in terms of a risk balanced research portfolio, speed of research output delivery and other hurdles that hold research translation back.

A critical assumption in this context is that beneficial price/cost models will be built by the research sector so that better relationships between industry/research provider relationships can develop

The proposed pilot innovation mentorship model with innovation mentors facilitating interactions between industry, and especially SMEs and funding research scientist salaries for research organisations researchers directly through the mentorship would be a

This means that for increased speed of implementation two smaller working groups could be more efficient. One of these two groups could focus on research translation and incentivisation and the other group on research process, efficiency and priority development.

Key implementation linchpins, risks and dependencies

Implementation of the Decadal Plan strategies needs to take into account the interdependencies between the recommended strategies. There are clear and specific linchpins in the strategic framework, that need to be implemented thoughtfully, efficiently and effectively because of the many other strategies that depend on their effective implementation. These linchpins, if not implemented successfully, will represent substantial risks to the success of the Decadal Plan.

The two, most critical, strategic linchpins are (a) the development of a common roadmap with a rolling R&D plan that supports successful adaptation and response of chemistry research, teaching and industry to emerging threats, challenges and opportunities, and (b) the appointment of a

Decadal Plan implementation committee with suitably qualified members that are able to work towards common goals.

Two other substantial risk areas are (a) getting agreement by research providers and industry on a risk-balanced research portfolio and (b) elimination of research translation hurdles. If agreement on new and mutually beneficial price/cost models cannot be developed, collaboration between the research sector and industry will not succeed.

A third area of risk is the ability to reach agreement on education goals in the primary, secondary and tertiary education sector. This will depend on buy-in by other stakeholder sectors, and especially by industry.

The other strategies which have a number of dependencies require new thinking, operations and models mainly in the higher education and research provider sectors but these strategies will require guidance by, and interaction with, the government sector.

This brief analysis of the structure of the strategic framework and the potential issues likely to be encountered during implementation needs to be substantially expanded to derive a 'bankable' implementation plan.

The key risks of this Decadal Plan lie in the ability of the chemistry stakeholder sectors to come together and work with a suitably qualified and motivated implementation committee towards, firstly a common roadmap and secondly towards lifting the effectiveness and efficiency of all the chemistry stakeholder sectors towards making larger contributions of the chemistry discipline possible towards a more competitive national economy.

Appendices

Appendix 1: National Committee for Chemistry

The Decadal Plan Working Group was overseen by the National Committee for Chemistry whose members (2014-2015) are listed below:

Prof Paul Mulvaney (Chair, University of Melbourne)
Prof Mark Buntine (2013-2014) President of the RACI, Curtin University)
Prof Paul Bernhardt (2015-2016 President of the RACI, University of Queensland)
Prof Evan Bieske (University of Melbourne)
Prof Michelle Coote (ANU)
Prof. Martina Stenzel (UNSW)
Dr. Regina Menz (Armidale HS)
Dr. Dave Winkler (CSIRO).
Prof. David Black (UNSW)
Dr. Oliver Jones (RMIT)
A/Prof. Rich Payne (USydney)
Dr Greg Simpson (CSIRO)
Dr John Lambert (Biota)

Appendix 2: Decadal Plan Terms of Reference

Inception

The proposal to undertake construction of a Decadal Plan was an initiative of the Australian Academy of Science in 2013. The proposal was embedded into the terms of reference for the National Committee of Chemistry of the AAS in mid-2013.

The Chair of the NCC then consulted with Heads of Chemistry at their annual meeting at ANU in October 2013. Their strong commitment to the process led to donations and funding of around $60,000 to begin the Decadal Plan development process[34].

In December 2013, a joint submission from the National Committees for Chemistry, Agricultural Science and Earth Sciences through the Learned Academies Special Programs (LASP) of the ARC secured further funding to enable the Decadal Plan to be undertaken. We thank the ARC for its commitment and support. The NCC formally agreed to undertake the process with funding in place at its meeting in December 2013.

Decadal Plan Terms of Reference

The Terms of Reference for the Decadal Working Group were defined as follows:

- To consult widely throughout all sectors of the chemical science value chain, from the primary school sector, through higher education, the research provider sector, regulators to industry and government policy makers.
- To provide strategic science policy advice, to the Academy, as input to Academy science policy statements, and (with the approval of the Executive Committee of Council) to the Australian Government and Australian organisations.
- To connect the Academy to chemical science and scientists in Australia;
- To ensure that Australia has a voice and a role in the global development of chemistry;
- To facilitate the linkage of the Academy to all sectors of the Chemistry value chain in order raise the relevance and viability of chemical science and to promote the development of the discipline;
- To facilitate the alignment of Australian chemical science to the global chemical science community and global scientific goals;
- To produce a decadal plan document for chemistry in Australia;
- Produce an implantation plan upon acceptance of the strategic direction of the Decadal Plan.

[34] Donations are listed in Appendix 8. Without this matching commitment it is unlikely the process could have been undertaken.

Appendix 3: - Decadal Plan Working Group

A potential list of working group members was drawn up in January 2014 and the final composition of the working group was finalised in March 2014. The WG was drawn from major stakeholders in the different states of Australia, different subsets and specialisations within the field and included representation from industry through PACIA and CSIRO as well as high school representatives.

The final Decadal Plan Working Group which prepared the report comprises:

Prof. Paul Mulvaney (Chair) (University of Melbourne)
Prof. Paul Bernhardt (University of Queensland)
Prof. Mark Buntine (Curtin University)
Mr. Peter Bury (PACIA)
Prof. Emily Hilder (U.Tasmania).
Ms. Samires Hook and Ms. Poulomi Agrawal (Australian Academy of Science).
Prof. Kate Jolliffe (University of Sydney)
Prof. Dianne Jolley (University of Wollongong)
Dr. John Lambert (Biota P/L)
Prof. Steven Langford (Monash University)
Ms. Regina Menz (Aust Catholic College Armidale)
Ms. Samantha Read (PACIA)
Dr. Elke Scheurmann (Rapid Invention P/L)
Prof. Joe Shapter (Flinders University)
Dr. Greg Simpson (CSIRO)
Ms. Alexandra Strich (University of Melbourne)
Prof. Brian Yates (ARC and UTasmania)

For hosting Decadal Plan Town Hall Meetings at their campuses, we also thank:

Prof. Peter Junk (James Cook University)
Prof. Barbara Messerle (UNSW),
Dr. Robert Robinson (ANSTO),

Appendix 4: - Australian Universities offering Bachelors degrees in Chemistry

The following 27 Australian Universities currently offer RACI accredited Bachelors degrees in Chemistry in 2015.

Macquarie University
University of New England
The University of Melbourne
Charles Sturt - BSc (analytical)
University of Newcastle
University of Sydney
University of NSW
University of Technology Sydney
University of Western Sydney
University of Wollongong
Flinders University
University of Tasmania
Griffith University
James Cook University
Queensland University of Technology (BAppSc)
University of Queensland
University of Adelaide
Deakin University - BForensicScience (hon.)
LaTrobe University
Monash University
RMIT University –BSc (Applied Chemistry)
Swinburne University
Victoria University
Curtin University
Edith Cowan University - BSc (Applied and Analytical Chemistry)
Murdoch University
University of Western Australia

Appendix 5: - Decadal Plan Process

Overall process

The Chemistry Decadal Plan is a document that is defining strategies for guiding future policy and investment in Chemistry research and development and it also aims to achieve a general improvement in Chemistry capabilities across the Chemistry value chain. To enable this to occur, the Decadal Plan Working Group employed a general business planning approach to its stakeholder consultation, analysis and strategic planning (Figure A1).

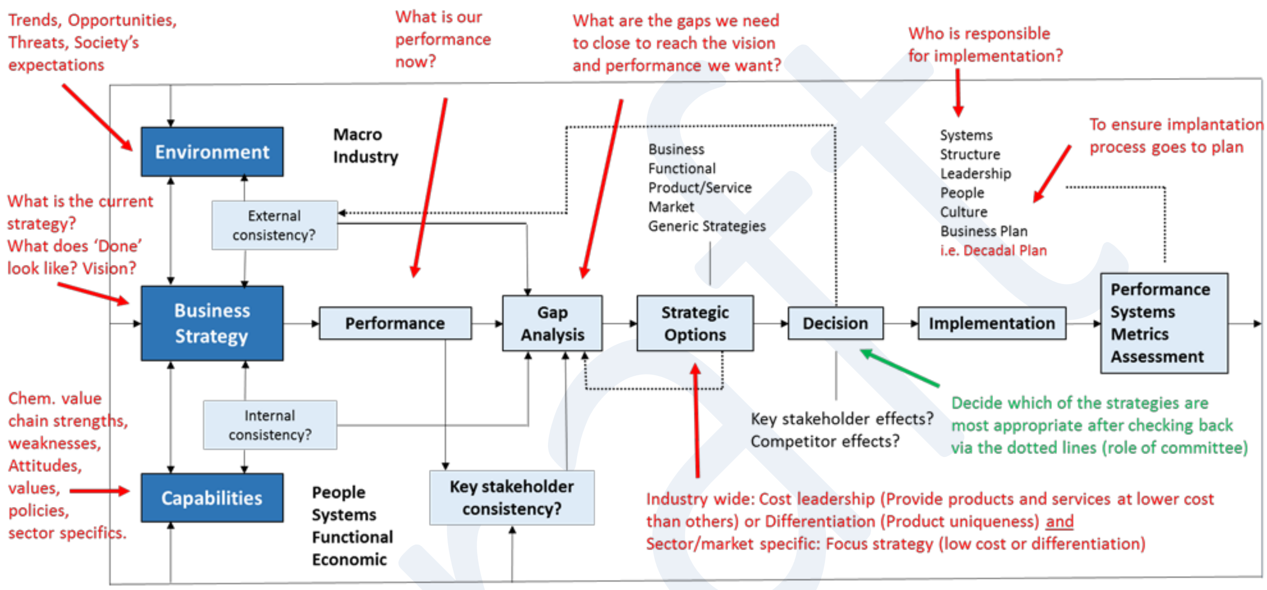

Figure A1: Decadal Plan Business Planning Approach, adapted from Graham Hubbard (2000) Strategic Management

The first step in this approach is to establish the current state of the field in Australia and overseas and to carry out a type of SWOT analysis. The current business strategic position was defined by using the outcomes of the 1993 Chemistry review, together with current government science and funding policies, and combining these with the current (PACIA) and research organisation strategic plans. The process steps needed to develop this strategic plan were then translated into a number of action steps as outlined below (Figure A2).

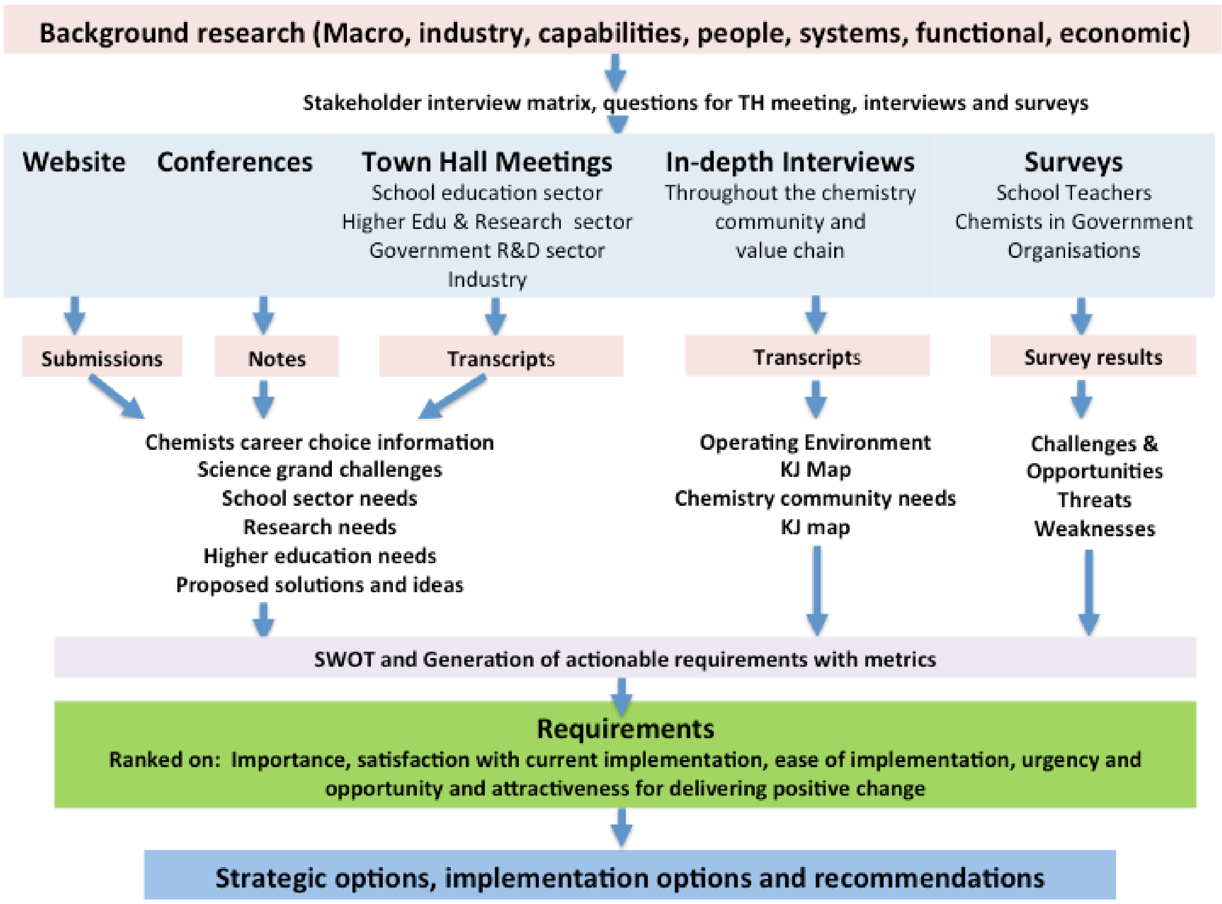

Figure A2: Decadal plan process translated into action steps

Background research

After analysis of the strategic position of the Chemistry value chain and determining which recommendations of the existing strategic plans have been adopted and implemented since 1993, an extensive background environment analysis was carried out about the Chemistry value chain in the national and international context. (Appendix 14).

This capability analysis of the Chemistry value chain, which consisted of further background research and intensive stakeholder consultation, provided the key information about the current performance and issues and requirements of the chemistry value chain. The process consisted of 6 strands for which different methods and approaches were used:

- 26 public meetings held across Australia covering Universities, research providers, and industry forums. The number of attendants at these meetings exceeded 700 people. A summary of these meetings is reported in Appendix 7.
- In-depth-interviews with 62 members of the chemistry community, ranging from school children to CEOs and government officials. This process covered all sectors of the Chemistry value chain. (See Appendix 6 for a list of interviewees and people consulted.)
- On-Line surveys of staff at major chemistry-based organizations such as the EPA, CSIRO, and of Science/Chemistry teachers across Australia. The analyses of these surveys is incorporated into the main Decadal Plan document.

- Attendance and discussions of the Decadal Plan Working Group members at a number of Chemistry and Science teacher conferences and forums.
- Email submissions to the Working Group. These were used for input into the overall capability and performance analysis
- Website submissions via a dedicated site (www.chemistrydecadalplan.org.au). These submissions were analysed and used as inputs into strategy development.

Town hall meeting process

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

In general, they were organised and promoted either by the relevant head of the organisation, the head of the Chemistry Department, the Dean of Science or a member of the National Committee for Chemistry or a member of the Chemistry Decadal Plan Committee. The industry meeting in Melbourne was organised and promoted by the BioMelbourne Network.

Each of the Town hall meetings was introduced by the Town hall 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.

Each of the meetings were 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 and issues that were 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.

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[35].

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

[35] Ulrich, Karl and Steven D Eppinger: Product design and development, 2011

in-depth, 25-90 minute long interviews were held, either by visiting the interviewees in their place of work or by phone.

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 the Appendix 11.

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"[36] and Karl Ulrich of the Wharton School at the University of Pennsylvania in 2003[37]. This method uses KJ diagrams[38] 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 (see Appendix 11) 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 outlines 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?"

[36] Burchill, Gary and Christina Hepner Brodie.: Voices into Choices. Joiner 1997
[37] http://opim.wharton.upenn.edu/~ulrich/documents/ulrich-KJdiagrams.pdf 2003
[38] 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/

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.

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 below.

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 & 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).

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

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 Survey Monkey 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 Survey Monkey survey.

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

1. ***Importance*** for them in their operating environment – from Zero (no importance at all) to 5 (extremely important).
2. **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 Kano[39]:

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.
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 in the lower left hand quadrant of Figure 3 and above the line labelled 1 is not productive and not cost-effective.

[39] 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/

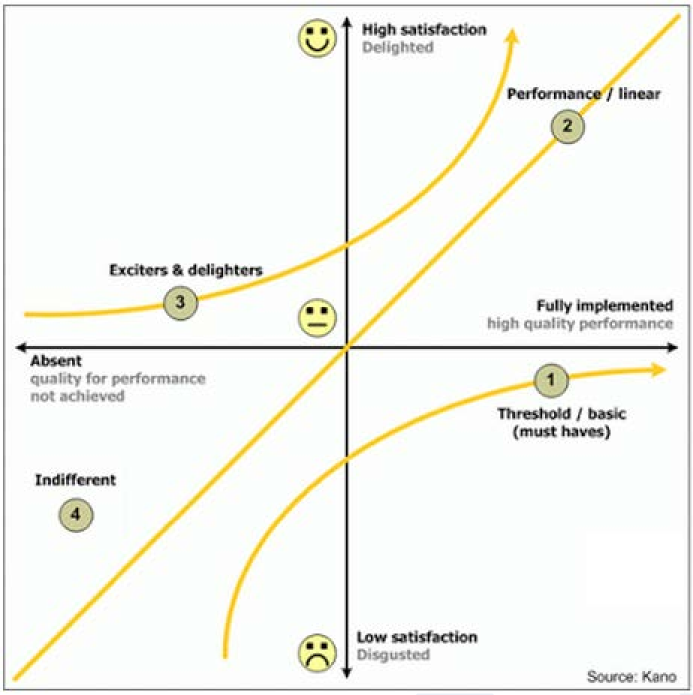

Figure A3: Typical Kano diagram

The top third and the bottom third of the requirements, based on their opportunity rank, were then plotted into a Kano diagram (Figure 4). The middle third of requirements were overlapping both red and yellow numbers and therefore have been left out of the diagram.

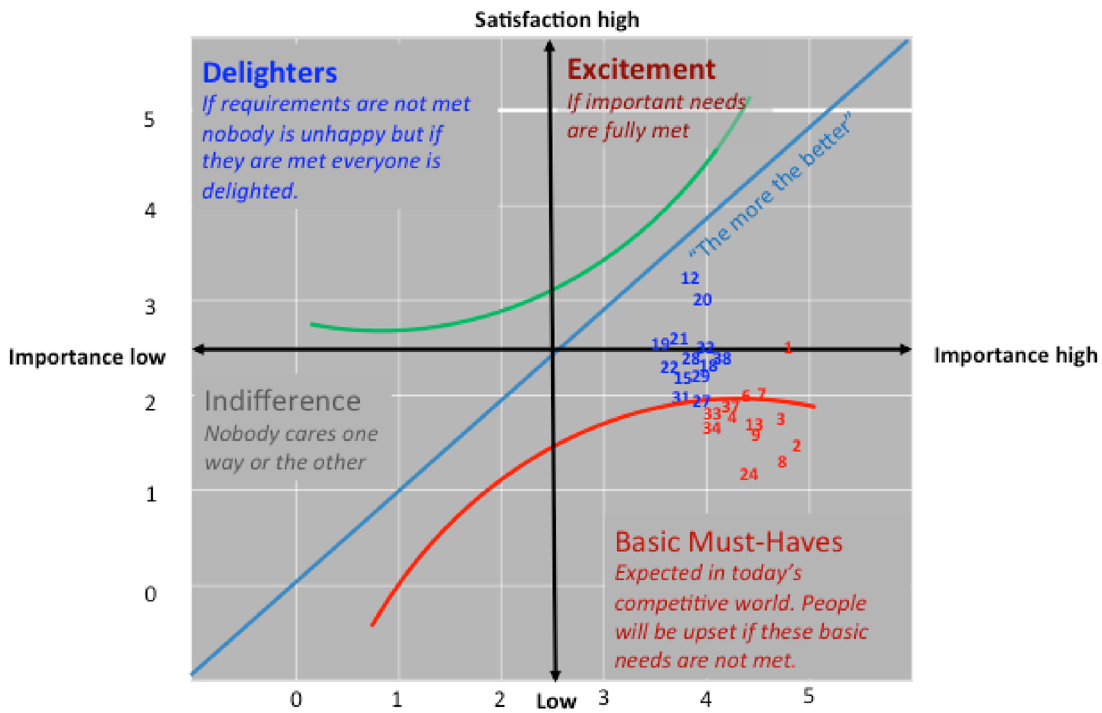

Figure A4: Kano diagram – We aim to identify all requirements that are either "must haves" or which lie under the "The more the better" performance line. This prioritizes "importance" over "excitement".

It can be seen that a large number of the requirements from the DP survey process were ranked close together. 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 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 “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).

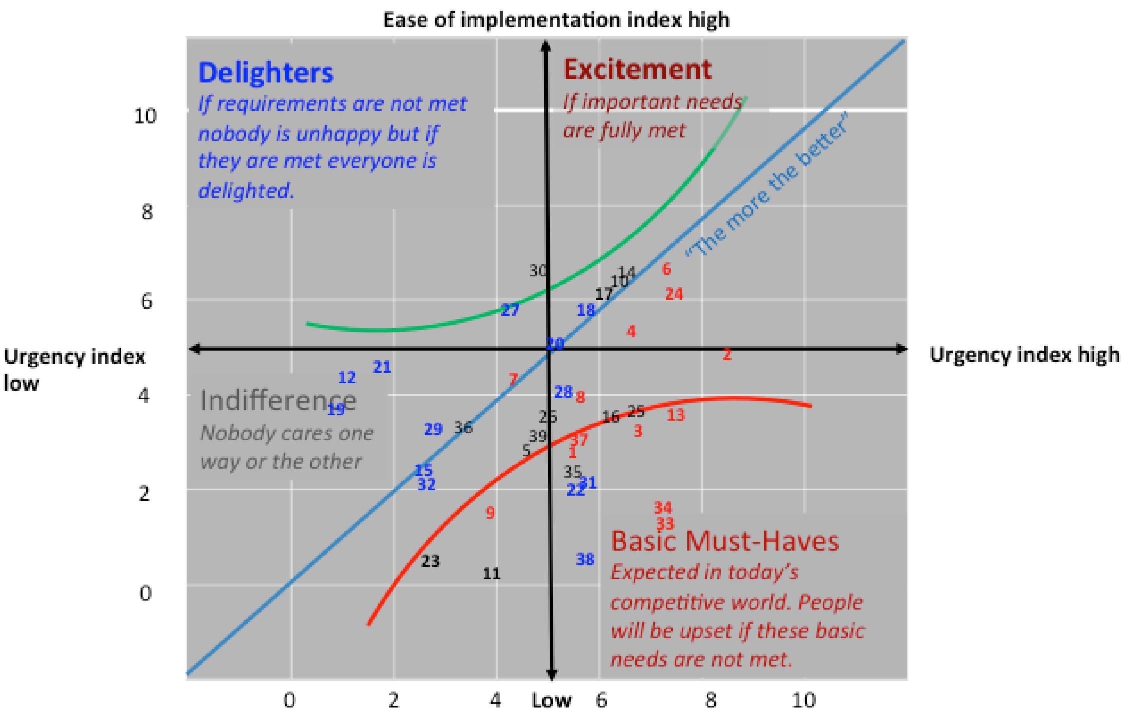

Figure A5: Kano diagram yielding a wider scattering of the requirements but most “must have” requirements are still “must have” requirements despite their issues with low or moderate implementability.

In summary, to try and prioritise the 39 requirements identified by the Chemistry sector, we hve first ranked them 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 can be 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.

The full list of requirements with the numbering as shown in the Kano diagrams is provided as Appendix 9.

Strategy Formulation

The Decadal Plan is fundamentally a bottom-up or grassroots document. It attempts to collect the experience, wisdom and insights of the experts and practitioners in the field and to get them to formulate the challenges they believe will best serve Australia. It is hopefully clear from the methodology applied that the Decadal Plan provides the sector with a mirror. It is not a policy document being imposed from without, but an internal assessment of the sector’s performance and aspirations.

The analysis of this information identified where current impediments in the interactions between the sectors is occurring and it also identified specific needs and specific requirements that need to be met to ensure that threats can be managed, new opportunities exploited and challenges and weaknesses overcome.

From this analysis a number of strategic options were developed so that chemistry stakeholder requirements can be met and which further enable the Australian Chemistry community and the overall value chain to adapt to the substantially changing global environment that will be operating over the next decade and beyond.

The number of strategic options is large but the decision of the decadal plan committee was to limit the number of strategic options to those that would be most “attractive”, i.e. enabling long term efficient, viable and profitable outcomes that also have high impact and are efficacious. The major basis for deciding on the strategic options chosen was the speed and ease of implementation, the effectiveness of delivering results, the ability to increase efficiency to world’s best practice and the ability to adapt in the future to the threats originating from the existing and emerging megatrends and threats.

Recommendations and Implementation process

The Decadal Plan Working Group made a small number of recommendations, based on the strategic options. However, in order to make recommendations, the strategic options should first be evaluated in terms of their implementability and cost of implementation. If implementation of some of the options is too expensive for the current financial position of individual sectors of the value chain or if the policy environment changes during the course of the coming decade, the strategic options need to be revisited.

The future implementation process has been addressed in ChapterVI of the Decadal Plan. Current consideration of it have been based on a number of assumptions , the primary one being that the strategies, as defined in the Decadal Plan, will be implemented at some stage during the coming decade, but as early as possible.

It was not possible to develop a solid budget for the implementation plan as this is beyond the remit of the Decadal Plan committee and requires the implementation of a Decadal Plan Implementation Committee that has the remit and capacity to develop budgets for implementation of each strategy,

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 – what are their 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 value chain" 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?

Appendix 6: - Individual People interviewed and consulted during the interview process

1. Mr Gary Smith, Senior principal engineer, URS Australia Pty Ltd
2. Mr Peter Kouwenoord, Laboratory and Product Development Manager, LyondellBasell Australia Pty Ltd
3. Mr Ross Pilling, Chairman & Managing Director, BASF Australia Ltd
4. Dr Markus Ehrat, KTI Innovation Mentor, Magden, Switzerland
5. Mr Nathan Fabian, CEO Investor Group on Climate Change
6. Mr Thomas Kerr, Director Climate Change Initiative, WE Forum
7. Wayne Best. Managing Director of Epichem, Murdoch, WA
8. Amanda Graystone, Chemistry teacher, Nossal High School, Victoria
9. Brendon Graystone, PhD candidate Monash
10. Prof Trevor Hambley, Dean of Science, The University of Sydney
11. Naomi Bury, Undergraduate Science student
12. Merion Harmon, Primary school teacher Northern Bay College, Corio Victoria,
13. Deanna D'Alessandro, Dept of Chemistry, The University of Sydney
14. George Carydias, Chemical Engineer, RMAX Australia.
15. Dr Gerry Wilson, CSIRO
16. Gwen Lawrie, Head of 1st Year Program, School of Chemistry & Molecular Biology, The University of Queensland
17. Associate Prof Andrea O'Connor, Chemical Engineering, The University of Melbourne
18. Mr Andrew Pascoe, Science teacher, Ceduna
19. Phil Davies, Senior Research Leader, DSTO
20. Ravi Naidu, CEO of the CRC CARE, Adelaide
21. Dr Paul Donnelly Senior Lecturer, School of Chemistry, The University of Melbourne
22. Robert Schofield Teacher NSW
23. Prof Graeme George, Polymer Chemistry QUT
24. Dr Lawrence Meagher, CSIRO
25. John Cerini, CEO Integrated Packaging
26. Ms Chloe Munro, Chair Clean Energy Regulator
27. Dr Clinton Foster, Geoscience Australia
28. Mr John Gunn, CEO AIMS
29. Ms Jane Cutler, NOPSEMA
30. Dr Brian Richards, Dept of Health etc. NICNAS
31. Dr Paul Grimes, Dept of Agriculture, Fisheries and Forestry
32. Ms Michelle Baxter, Worksafe Australia
33. Dr Johnathan Palmer, ABS
34. Dr Adrian Paterson CEO ANSTO
35. Dr Alex Zelinsky DSTO
36. Dr Rob Vertessy, CEO BOM
37. Dr Rosanna DeMarco, Dow Chemicals
38. Mr Patrick Houlihan, Dulux
39. Lauren Reader, University of Melbourne
40. Greg Chow, The University of Melbourne
41. Mr Mick Moylan, Chemistry Outreach Program, The University of Melbourne

42. Prof Rose Amal, Head of School of Chemistry, University of New South Wales and Director of the ARC Centre of Excellence for Functional Nanomaterials
43. Dr Cameron Shearer, Postdoc, Flinders University
44. Dr Deanna D'Alessandro, Lecturer, School of Chemistry, The University of Sydney
45. Dr Max Massi, Senior Lecturer, Dept of Chemistry, Curtin University
46. Dr Angus Netting, MD Adelaide Microscopy
47. Mr Nigel Brookes, Science Teacher, Guilford Young College, Tasmania
48. Dr Richard Muscat, DSTO Melbourne
49. Dr Shaun Smith, Project Manager, CSIRO
50. Dr Brett Roman, GHD Australia
51. Dr Katrina Frankcombe, The Garvan Institute
52. Mr Mike Pointon, Manager Innovation & Development, Nufarm
53. Dr Dana Johnson, CSIRO AAHL.
54. Phillipa Pearce, Teesdale Primary School
55. Jacinta Branson, Geelong College
56. Christopher Gulle, St Joseph's College, Newtown, Victoria
57. Andrew Gulle, Welder, Bamganie, Victoria
58. Sandra Haltmayer, Steinbeis GmbH Suttgart, Germany
59. Uwe Haug, Steinbeis GmbH, Stuttgart, Germany
60. Ms Meron Southall, Primary school science teacher, Teesdale Primary School, Victoria
61. Mr Tony Gove, Principal Teesdale Primary School, Victoria
62. Dr Chris Such, Research Manager, Dulux Australia
63. Dr Philip Leslie, Site Technical Lead, GlaxoSmithKline Australia, Boronia
64. Dr Jenny Sharwood (retired)
65. Dr Ian Dagley (CEO for the CRC for Polymers)
66. Dr Danielle Kennedy (CSIRO)
67. Dr Sean Murphy, University of Melbourne
68. Dr Uta Wille, University of Melbourne
69. Dr Robert Robinson, ANSTO
70. Dr Richard Thwaites (retired)
71. Dr Curt Wentrup, University of Queensland
72. Dr Fabien Plisson, University of Queensland
73. Dr Megan Cook, Dept. Health, Queensland
74. Prof Peter Karuso, Macquarie University
75. Dr David Edmonds

Appendix 7 - Locations and Dates of Town Hall Meetings

Public, Town hall meetings were held at 26 locations across Australia as part of the Stakeholder consultation process.

	Town hall Meeting	Date	Location
1	CONASTA High School Conference	July 9, 2014	Adelaide, SA
2	The University of Melbourne	July 29, 2014	Melbourne, CIC
3	Flinders University, South Australia	August 19, 2014	Adelaide. SA
4	University of Technology Sydney (UTS)	August 20, 2014	Sydney, NSW
5	Monash University	August 20, 2014	Melbourne
6	The University of Sydney	August 27, 2014	Sydney
7	Opal Auditorium, ANSTO,	August 28, 2014	Lucas Heights, NSW
8	University of New South Wales	August 28, 2014	Sydney
9	Women in Chemistry	September 2	Melbourne
10	South Australia RACI Branch Meeting	September 15, 2014	Adelaide
11	University of Queensland	September 15, 2015	St Lucia, QLD
12	SETAC Asia-Pacific 2014	September 16, 2014	Adelaide
13	Charles Darwin University	September 22, 2014	Darwin
14	CSIRO - Clayton	October 9, 2014	Melbourne
15	Charles Sturt University	October 10, 2014	Wagga Wagga
16	Industry Forum on The Future of The Chemical Industry In Australia	October 14, 2014	Brisbane
17	University of Adelaide	October 14, 2014	Adelaide
18	Curtin University	October 22, 2014	Perth
19	University of Western Australia	October 31, 2014	Perth
20	Queensland University of Technology	November 6, 2014	Brisbane
21	Griffith University	November 13, 2014	Griffith
22	BioMelbourne Network Breakfast: ‘Future of Chemistry, Future of Manufacturing’	November 25, 2014	Melbourne
23	University of Wollongong	November 25, 2015	Wollongong
24	QUT – STAQ Annual Workshop – A Forum for Qld Chemistry & Science Teachers	November 28, 2014	Brisbane
25	Australian National University	December 4, 2014	Canberra
26	RACI National Conference	December 8, 2014	Adelaide
27	James Cook University, Townsville and Cairns (via Weblink)	December 9, 2014	Townsville and Cairns

Appendix 8: - Organisations consulted

Universities

University of Melbourne
University of Queensland
Monash University
University of Sydney
University of Wollongong
University of New South Wales
Australian National University
Flinders University
Curtin University
University of Western Australia
Griffith University

Education Providers

Science Teachers Association of Queensland (STAQ)
Science Teachers Association of Victoria (STAV)
Conference of Australian Science Teacher Association (CONASTA)

Research Institutions

CSIRO
ANSTO
DSTO
The Australian Synchrotron
Melbourne Centre for Nanofabrication

Industry Organizations

Dulux-ICI
CRC for Polymers
The BioMelbourne Network
PACIA

Other Lead Organizations

Royal Australian Chemical Institute (RACI)
Women in Chemistry
Australian Technological Sciences (ATSE)

Government Organizations

The Office of the Victorian Lead Scientist
The Office of 'The Chief Scientist'

Sponsors

The National Committee for Chemistry gratefully acknowledges financial support and donations from the following organisations, to help cover the costs of preparation of this report:

- The ARC through its Learned Academies Science Policy (LASP) program.
- The Australian Academy of Science – Policy Development Office.
- The Schools of Chemistry at the Universities of Queensland, Melbourne, Sydney, NSW, Monash, Curtin, Flinders and the AIBN at the University of Queensland.
- The Royal Australian Chemical Institute (RACI).

Appendix 9: - List of Requirements

From the analysis of the Town hall meetings, interviews, and submissions, a set of requirements were drawn up that were ranked using the process outlined in Appendix 5.

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

Rank #	Requirement / Desired outcome or solution	Mean importance (0-5)	Mean satisfaction (0-5)	Opportunity index (1-10)
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

Rank #	Requirement / Desired outcome or solution	Mean importance (0-5)	Mean satisfaction (0-5)	Opportunity index (1-10)
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

Rank #	Requirement / Desired outcome or solution	Mean importance (0-5)	Mean satisfaction (0-5)	Opportunity index (1-10)
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

Appendix 10: - Pilot scheme for R&D project mentorship for chemical SMEs

The Decadal Plan contains a recommended pathway for implementing a pilot program for enabling chemical industry companies, and especially SMEs, to facilitate faster innovation and increased competitiveness of the sector via faster development of more high-end products, processes and services. This recommendation is based on the scheme delivered through the Swiss Commission for Technology Innovation (CTI) model[40].

Objectives of the CTI scheme

The CTI aims to generate more innovative products and services by motivating higher education institutions and the private sector to carry out application-oriented R&D projects together. Hundreds of such projects are supported every year.

The CTI provides funding based for projects on the following principles:

- The project partners define their own projects
- Projects contribute to establishing Switzerland as an investment grade centre for business and research and improve the competitiveness of the economy.

Companies benefit from the expertise of young, trained researchers, and access to the infrastructure of the higher education institutions for their projects. Project grants are open to all disciplines and assessed by relevant experts in four main subject areas. Approved projects demonstrate the greatest potential for knowledge generation and added value.

Scheme funding supports the salaries of around 1000 researchers each year. The CTI generally pays just for the research institution salaries and some related research costs in the research institution. The company is expected to pay at least 50% of the project costs (including cash and in kind costs).

Eligible Research facilities/partners for R&D projects

- Higher education and research sector
- ETH Domain (Technical higher education institutions)
- Non-commercial research facilities outside the higher education sector (recognised by the CTI)

How to apply for an R&D project

The application process has eight steps:

- Step 1: Compose your project team
- Step 2: Find out more about your research topic
- Step 3: Develop a project plan

40 R&D projects for your company. https://www.kti.admin.ch/kti/en/home/unsere-foerderangebote/Unternehmen/f-e-projekte.html

- Step 4: Submit the application
- Step 5: Application processed
- Step 6: Decision
- Step 7: Statutory requirements
- Step 8: Signing the contract.

In Step 1, it is possible for a company that has already an idea for technology innovation to submit an application for an R& D project. However, if the company has an idea but not yet developed connections with a research organization but wants to get started, they can apply for a CTI voucher41, which gives companies the opportunity to submit a research and development project funding application without specifying a research partner. This is particularly important for SME's that want an expert assessment of their innovation project and help with looking for a research partner.

It is also possible for a company that has limited experience with R&D and/or no specific project ideas to get started by submitting an application for an innovation cheque (CHF 7,500 for one year). This funding supports initial interactions with research providers for feasibility testing of ideas. Innovation cheques are used to contribute towards the costs incurred by the **research partner** for services provided, i.e. salaries, material costs, travel expenses4243

Once a project is approved, the company is responsible for driving its completion as quickly as possible and according to milestones. An implementation audit is conducted 18 month after the end of the project to assess the value created through the project.

There are two key requirements for the successful implementation of this scheme:

- An expert panel for the research area in which the application is submitted, and
- Innovation mentors.

Expert panels

Each of the main innovation areas has an expert panel that, on a monthly basis, assesses applications for innovation cheques, vouchers, and R&D projects.

Each panel is composed of between 12 and 15 experts from Swiss industry and the research sector.44

Innovation mentors (IM's)

The IMs help companies and public research institutions to jointly launch science-based innovation projects of national and international significance.

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41 CTI Voucher: submit an application without a research partner.
[42] Innovation cheques for SMEs. file:///C:/Users/Elke/Downloads/General%20conditions%20innovation%20cheque.pdf
[43] Innovation cheque flow chart. file:///C:/Users/Elke/Downloads/Process%20innovation%20cheque.pdf
[44] KTI-Expertenteams 2014. file:///C:/Users/Elke/Downloads/M_Expertenliste_F&E_2014_de.pdf

IMs inform companies of the funding opportunities open to them and help them to draw up CTI project proposals. The mentors also facilitate cooperation between companies and public research institutes in science-based innovation projects of national and international importance.

The service provided by IMs is directed primarily at R&D-based, innovation-oriented businesses. Their services are provided free of charge to the company and are paid by CTI.

Innovation mentors, because of their innovation expertise gained in R&D-heavy commercial companies are able to answer the following questions for a company that wants to embark on an innovation project[45]:

- Our company has an innovative idea but we are lacking in research expertise. Where and how do we find this?
- Who can give me an overview of the different funding institutions for innovation projects?
- Which research institution would be the best partner for my innovation project?
- Does my project have a chance of attracting CTI R&D funding?
- Is my company actually eligible to receive CTI funding for innovation projects?
- What factors are involved in successfully launching my innovation on the market?
- What, if any, contractual agreement exists between me and my research partner?
- How do I draw up a project application for the CTI and how do I sort out patent issues with my contractual partner?

The qualifications and experience of Swiss Innovation Mentors are very high[46]. The main focus is on having long-term, in-depth expertise in higher positions in the commercial sector in R&D focused companies that have a track record of bringing products and services to the market in reasonable time frames and creating substantial revenue for the companies they worked for. They have to be independent and respected by both the SME sector, larger companies, the research sector and government agencies.

Consequently, most of the Swiss IMs are 50 years and older, with a mix of experience with major industry companies and with spinning out start-ups. All current Swiss IMs work in the commercial sector and not in government or in the research provider sector. The major difference between the Swiss IMs and Australian innovation support specialists is the much longer and in-depth technology/new product development expertise in multinational and large companies.

Costs of the Swiss CTI funded R&D and Innovation Mentorship scheme.

The Swiss system is heavily SME focused. Of the 553 commercial companies receiving R&D support via the CTI, 71% are SMEs and in 2014, 54% of the companies were involved with the scheme for the first time.

Funding to the research sector for the research projects under this scheme totaled CHF 117. 1 million for a total of 362 R&D projects to which industry contributed CHF 141.2 million.

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[45] Innovation mentors: partner and support for your business. https://www.kti.admin.ch/kti/en/home/unsere-foerderangebote/Unternehmen/beratung--innovationsmentoren.htmlind

[46] Anforderungsprofil KTI Innovationmentor/in (IM). file:///C:/Users/Elke/Downloads/Profile%20innovation%20mentor%20(in%20German)%20(1).pdf

On average, the expenditure by the CTI for an R&D project under this scheme is estimated at CHF 335,000 per annum for a new project.

The research mentorship scheme expenditure (13 innovation mentors) for support of the industry-research provider interaction was CHF 1 million in 2014, plus CTI support for the mentorship scheme.

Proposed Australian Innovation Mentorship Pilot Program

As part of the strategic goal 3 of (Raise the level of research and innovation efficiency and improve the translation of research results) this plan recommends the implementation of a pilot innovation mentorship program for facilitating better and more targeted technology transfer between the chemistry research community and industry (and especially SMEs).

The proposal is for two innovation mentors (one in the biotech/biosciences/agricultural etc chemistry, and one in the petrochemical based/mining chemistry based backgrounds), preferably with chemical engineering knowledge or links to chemical engineering.

They should be based in a location where the chemical industry has some critical mass in these areas, with both large companies and SMEs being established in large enough numbers and connections to one or more relevant chemistry industry growth centres and high-end research infrastructure.

Benefits of the Innovation Mentorship Scheme

The expected benefits of the innovation mentorship scheme are:

- A critical mass of new young and trained research scientists will be employed on industry projects who otherwise would not be exposed to industry research, and especially the innovation needs of SMEs.
- SMEs will be trained in R&D and new product development by Innovation Mentors who have substantial expertise in both industry R&D and new product development, as well as with the global and national chemical industry and innovation landscape.
- The hurdle that SMEs see in not being able to afford research scientists' salaries will be broken down. They will be able to afford the R&D project as the research scientist salary expenditure is payed directly by the mentorship scheme to the research institution.
- Closer connections and interactions between industry and the research sector will be formed that contribute to a more seamless collaboration between the two sectors.
- The level of SME R&D efficiency and innovation capability will be raised.
- The level of R&D provider research efficiency and research translation capabilities will be raised.
- Existing manufacturing capabilities of the Australian industry landscape will be leveraged through increased focus on science based product, process and service innovation. This will add value to the Australian economy once this pilot scheme has been successfully implemented as a viable innovation model.

Appendices 11 to 14 in Part 2 of the Decadal Plan

Appendices 11 to 14 are provided as Part 2 of the Decadal Plan, for download from the website

[Insert link here]

Appendix 11: Town Hall Meeting Summary (in Part 2)
Appendix 12: Current Issues, Critical Success Factors and Opportunities for the Future (in Part 2
Appendix 13: Survey results Chemistry Teachers (in Part 2)
Appendix 14: Survey results Chemists in Government (in Part 2)

List of Abbreviations

AFFRIC	Australian Future Fibres Research and Innovation Centre
ANFF	Australian National Fabrication Facility
ANSTO	Australian Nuclear Science and Technology Organisation
APVMA	Australian Pesticide and Veterinary Medicines Association
ARC	Australian Research Council
ATSE	Academy of Technological Sciences and Engineering
CEO	Chief Executive Officer
CFC	Chlorofluorocarbon
CO2	Carbon dioxide
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DDT	Dichlorodiphenyltrichloroethane
DECHEMA	DECHEMA Gesellschaft für Chemische Technik und Biotechnologie e.V. (Society for Chemical Engineering and Biotechnology)
DNA	deoxyribonucleic acid
DSTO	Defence Science and Technology Organisation
E7	Group of 7 emerging economies
EPA	Environment Protection Authority
EU	European Union
FTE	Full Time Equivalent
G7	Group of 7 advanced developed economies
GFC	Global Financial Crisis
IMBL	Imaging and Medical Beamline
LED	Light-emitting diode
MCN	Melbourne Centre for Nanofabrication
NHMRC	National and Health Medical Research Council
NICNAS	National Industrial Chemicals Notification and Assessment Scheme
OECD	Organisation for Economic Co-operation and Development
OH&S	Occupational Health and Safety
OPAL	Australia's Open Pool Australian Lightwater (OPAL) reactor
PACIA	Plastics and Chemical Industries Association
PISA	Programme for International Student Assessment of the OECD
RACI	Royal Australian Chemical Institute
R&D	Research and Development
SME	Small and Medium Enterprises
STEM	Science, Technology, Engineering, Mathematics
TAFE	Technical and Further Education
TGA	Therapeutic Goods Association
TIMMS	Trends in International Mathematics and Science Study
UK	United Kingdom
VCAMM	Victorian Centre for Advanced Materials Manufacturing
WEF	World Economic Forum
WHS	Work Health & Safety

Figures for the Decadal Plan

Additional figures of high quality need to be inserted into final exposure draft in appropriate pages to show the value of Chemistry and support the content of the various sections.

They need to be in the public domain or donated by members of the Chemistry Community royalty free.

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