The Complex Futures of Emerging Technologies: Challenges and Opportunities for Science Foresight and Governance in Australia

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Abstract

This paper outlines trends in the development of high-profile new technologies such as nano- and bio-technology, identifying roles foresight and governance practices must play to enable their usage in addressing 'wicked' problems (e.g. climate change). We explain the notion of emerging technologies, and their expected convergences, and consider both their potential and issues faced in the Australian context. Recent trends and emerging issues – such as slower, more problematic development and adoption than expected, and increasingly global competition to establish 'future industries' – are reviewed to identify a set of imperatives. These imperatives highlight emerging opportunities and challenges, focussing on how examining alternative futures and perspectives may help enable effective responses to emerging technologies.

Keywords: emerging technologies, wicked problems, governance, expectations, convergence

Introduction: 'Nano-Bio-Info' and Beyond

This paper considers the future development of emerging technologies and their potential contributions in the Australian context. 'Emerging technologies' are commonly associated with nanotechnology and biotechnology (Australian Government, 2010; Australian Institute for Commercialisation, 2011), and also expected to converge with other areas such as information and communications technologies (ICT) and cognitive science. Broadly speaking, 'nanotechnologies' exploit knowledge of the nanoscale and related technological capabilities, and 'biotechnology' refers to "the application of science and technology to living organisms, as well as parts, products and models thereof, to alter living or non-living materials for the production of knowledge, goods and services" (OECD, 2005). These technologies are mostly in early phases of development (e.g. see Palmberg et al., 2009) and are the focus of the Federal Government's *National Enabling Technologies Strategy* aimed at developing new, convergent technologies that are viewed as having the potential to provide long-term social and economic benefits (Australian Government, 2010). Currently, activity in Australia is *primarily* research-oriented, rather than commercially developing and/or adopting such new technologies (Australian Academy of Science, 2009; Australian Government, 2011).

Policy and scientific agendas aiming to advance emerging technologies are also rapidly evolving. Nanotechnology was the central focus in the early-to-mid 2000s (Australian Government, 2008b; PMSEIC, 2005; Royal Society & Royal Academy of Engineering, 2004; Tegart, 2002), however, many additional foci are developing. Current agendas reflect hopes for breakthroughs in diverse areas such as energy supply, environmental remediation, and manufacturing.

This paper is structured as follows. First, the notion of emerging technologies is explained along with related trends. Second, 'hopes' for these potential technologies articulated by Australian players are outlined and placed in the context of 'wicked' problems. Evolving social contexts in Australia and Asia-Pacific in which emerging technologies may be developed are then described. Finally, a set of core imperatives are identified that highlight related emerging opportunities and risks based on observed trends and the authors' own relevant experiences.

Emerging Technologies: Characteristics, Trends and Issues

Contemporary emerging technologies can be distinguished from earlier waves of technological change in three respects. They tend to be *laboratory-based*, requiring major expenditures on research that differs from traditional 'pure' or 'basic' scientific research; *transdisciplinary* in their underlying knowledge, therefore requiring knowledge and skills from a wide variety of specialist fields to progress from research to the production of commercially successful products; and, *generic in scope*, meaning they have a wider range of potential functions and applications than earlier waves of technological capabilities, and can consequently be viewed as generic "solutions in search of problems" (Jamison & Hård, 2003, pp.84-5) or as 'platform' technologies (Department of Innovation, Industry, Science and Research, 2011). This latter aspect also has the problematic consequence that emerging technologies tend to be supply-driven, not demand-driven (Jamison & Hård, 2003). This aspect is also significant in the context of tentative shifts away from science/technology-push approaches and towards participatory foresight and related models of technology development

(McGrail, 2010; Ozdemir et al., 2011). These characteristics can also make today's emerging technologies more challenging to develop.

These technological domains are also often described as being 'converging' technologies and as 'enabling'. For example, Nordmann (2004, p.14) observed that:

> Nanotechnology can be said to bring about, by itself, a convergence of domains. It is common knowledge, after all, that all material things are made out of atoms and molecules. Nanotechnology enables one to engineer at the nanoscale and thereby perhaps to reconfigure everything molecular. From the point of view of nanotechnology, what used to be separate domains … come together in a single engineering paradigm.

Similarly, Tegart (2010) highlights that emerging technologies often involve bringing together a range of technologies and fields of research, which generates new, related fields of interest and possibilities where they connect (see *Figure 1* for an example). This is true for the framing of 'enabling' technologies in Australia (Australian Government, 2010), as well as the concept of 'converging' technologies discussed in the United States and Europe (Nordmann, 2004; Roco & Bainbridge, 2002).[2] However, the US framing tends to be more radical, such as embracing technologies to 'enhance human performance' (e.g. via brain implants that enhance cognitive performance). One issue faced is the rapidly increasing degree of technological complexity and the uncertainty generated by potential 'convergences' (Petersen, 2011). A second key issue raised by Tegart (2010) is the increasing need to change the tendency toward 'technology push' (e.g. through more user-centric approaches). This is due to the increasing potential for ethical concerns and social considerations regarding development and adoption.

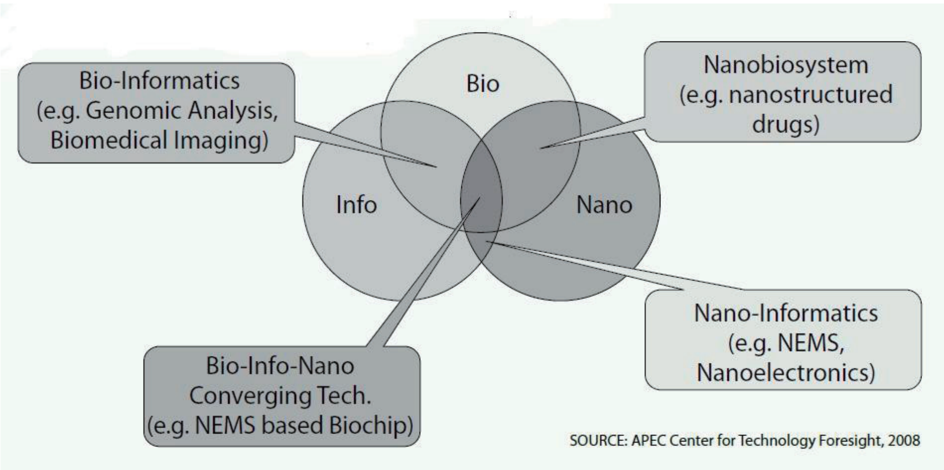

Figure 1. Examples of the convergence of technologies in biomedical/biosecurity applications
Source: Tegart (2010) – N.B. 'NEMS' = 'Nanoelectromechanical Systems'

Worldwide, there is a developing tendency to discuss 'emerging technologies' rather than the separate entities (e.g. nanotechnology, information technologies, etc). The transdisciplinary and convergent characteristics are drivers of this. It is also fair to say that emerging technologies are often vaguely defined, such as purely by perceived novelty or as commercially important areas of emerging science. Overall themes are summarised in *Table 1*.

Table 1. *Key themes in emerging technologies*

Theme	Definition/relevance
New, emerging, developing	The technology or underpinning science is a new discovery or application, or not yet well understood.
Enabling capabilities, applications	The application of the technology facilitates a solution.
Convergence, multidisciplinary	Comprises knowledge from multiple disciplines, and most-likely crosses over traditional science disciplines.
Integration, systemic	The technology is likely to be partnered with other technologies and knowledge as part of a broader solution.
Market, SMEs, employment, economy, environment, social	It exists in a commercialisation context: there is an expectation that technology has commercial potential and will exist within a broader context of uses, applications, and issues.
Highly-skilled, knowledge	Requires a higher level of skill than for traditional industries (i.e. more science-based and -intensive products).
Addressing, applications, relevance	Provides something needed by consumers or broader society.
Rapid, acceleration	Sense of speed (e.g. accelerating technological progress), and/or accelerating progress towards solution to difficult problems.

Source: Authors' analysis derived from literature review

Recent trends

As indicated in the introduction, scientific and policy agendas for advancing emerging technologies have significantly changed over the past decade. The focus on nanotechnology in the late 1990s and early 2000s resembled a "global technology race" (National Science and Technology Council, 1999) and became an "unprecedented global technological movement" (Schummer, 2008). Recently new labels and domains have grown and nanotechnology appears to be declining, especially as a central mobilising term (McGrail, 2011).

Biotechnologies are increasingly discussed within 'synthetic biology', converging science and engineering with the aim of "designing and constructing new biological systems not found in nature" (Schmidt et al., 2009). Major changes in our capacity to synthesize viruses and bacterial genomes, with a view to routinely synthesising 'designer' genomes, are forecast by involved scientists and entrepreneurs. In this way, it can also be seen as an evolution of genomics.[3] According to Leys (2012), "the promise ... lies in the ability to rewire or reprogram organisms and their molecular systems, aimed at creating practical applications in energy, environment and health", which is "fundamentally different from what can be achieved through selective breeding or simple biotechnology" because it is not limited by the existing gene pool.

In terms of policy agendas, aims to realise industrial scale biologically-based innovation have begun to be discussed within the goal of establishing 'bioeconomies'.

The desired outcome is for biotechnologies to contribute a significant share of economic output through the invention, development, production, and use of biological products and processes (CSIRO, 2008; OECD, 2009, 2010). Such a bioeconomy could be developed around "the use of advanced knowledge of genes and complex cell processes to develop new processes and products, the use of renewable biomass and efficient bioprocesses to support sustainable production, and the integration of biotechnology knowledge and applications across sectors[e.g. energy, healthcare]" (OECD, 2009, p.8). The OECD (2009; 2010) advocates far greater focus on this agenda in order to realise by 2030 improved productivity in agriculture and industrial processes, health outcomes, and environmental sustainability.

Since 2005 'cleantech' has also entered the language in technology development and become a major focus of venture capitalists and entrepreneurs. 'Cleantech' draws on new materials, systems and related science in order to address issues of energy security and sustainability (Alford & O'Brien, 2010). New solutions seek to optimise use of natural resources and reduce environmental impacts whilst delivering value (e.g. new electric vehicle systems). Overall, these trends highlight the dynamic nature of the emerging technologies space.

Australian Hopes for Emerging Technologies in the Contemporary Context of 'Wicked' Problems

Emerging technology domains – such as those outlined above – are largely in the early phases of development and, as such, their precise futures are unknowable. Despite this intense uncertainty they are widely considered to offer considerable promise in the context of national and global, challenges (Australian Institute for Commercialisation, 2011). Others foresee major perils (e.g. see McGrail, 2010; 2011; Miller et al, 2006; Miller & Senjen, 2008; Sheppard et al., 2011). Furthermore, as Nordmann (2004, p.7) observed, "transformative potential comes with tremendous anxieties" that increasingly "need to be taken into account" if such technologies are going to developed "in a supportive climate". This section outlines some of the hopes for such technologies voiced by Australian scientists and thought leaders and introduces the concept of 'wicked' problems, as a key contextual consideration.

Australian hopes for emerging technologies

A wide range of 'hopes' for emerging technologies are being articulated in Australia. These tend to focus on solutions to current concerns, such as mitigating and adapting to climate change, and the implications of a rapidly ageing population. A selection is presented in *Table 2*.[4]

Table 2. *Hopes for emerging technologies articulated in the Australian context*

Category	Focal domain	Example Envisioned Applications	Potential Scenario(s)
Advanced ICT	Gerontechnology: high-tech assisted ageing	• Smart homes that minimise falls and other accidents (e.g. house fires) • Real-time health monitoring • Remote e-health/tele-health services	• 'Ageing-in-place' assisting the aged to live independently for longer and greatly reducing healthcare costs
	Precision agriculture	• Smart sensors nodes remotely collecting information such as plant behaviour, environmental conditions, etc • Enabling technologies such as global positioning systems, yield monitors	• More water-efficient agricultural production • More automated agriculture meeting increasing demand in context of rural decline
The Built Environment	Nanotechnology and new materials	• Self-cleaning and self-healing materials • Improved materials: e.g. light-weight materials (such as geo-polymers); better corrosion resistance; and advanced properties (e.g. antimicrobial) • Energy conversion, storage, distribution technologies: e.g. catalysts, new advanced photovoltaics (such as 'organic' solar cells) • Nano-electronics (e.g. smaller sensors)	• Radically localised energy generation, such as via paint-able' solar technologies applied to buildings and outdoor solar structures (e.g. new wall coatings, covering conventional glass, etc) • Built environments able to adapt to future climates
	Environmental nanophotonics: nanoscience for energy efficiency and environmental sustainability	• Painted "cooling" coatings that reduces energy demand (e.g. of buildings through use of "cool roof" applications) • Switchable/'smart' surfaces, which switch properties according to conditions/needs • 'Nano-structured' windows for more energy efficient buildings	• Reduced urban 'heat island' effect via 'cooler suburbs' created by applying nano-structured roof coatings to all buildings to reflect heat • Reduce "peak load" energy demand during summer

Biotechnology and the environment	Biotechnology and energy, industrial production (e.g. via synthetic biology)	• Petroleum and diesel fuel substitutes • Converting lignocellulosics to ethanol; algae to biodiesel technologies • Bioindustry-focused GM and engineered crops of high industrial value	• Liquid transport fuel security achieved without impacting food production/ security • Bioeconomy mitigating future oil shocks/price rices
	Biotechnology and food production	• Genetic modification (GM) to change characteristics (e.g. yield, pathogen and pest resistance, nutritional fortification) • Use of non-GM plant breeding-based e.g. marker-assisted selection (MAS), phenomics (involving plant phenotyping), and marker-assisted recurrent selection (MARS).	• Access to well-priced essential foods, for rapidly expanding global population (e.g. via new crop capabilities)
Nano-bio-technology	Nano-biotechnology in the human body	• Use of nanomaterials (e.g. dendrimers) and specific dyes/ materials to enable imaging and new drug delivery methods • Needle-free modes of drug delivery • Bionic eye (functional, artificial eye)	• Earlier cancer detection and reduced side-effects from cancer treatment • Improved, less-invasive medical treatments and cures for more major diseases
Cleantech	New solutions for energy, water, and transportation	• Biomimicry inspired next-generation wave/tidal power systems • Adaptation of water purification technologies (e.g. solar-powered water desalination; solar filtration for potable or grey water treatment) • Biosequestration technologies • Functional 'green wall/roof' systems	• New energy technologies well-suited to Oceania and Asia-pacific region (esp. wave/ geothermal) • Distributed renewable baseload power (e.g. using undervalued biomass as energy source) • Affordable, low-tech energy addressing 'energy poverty'

Source: Adapted from various sources (including Australian Nanotechnology Alliance, 2008; Department of Innovation Industry Science and Research, 2009; Gentle & Smith, 2010; Lu & Tegart, 2008; Smith, 2011; Smith & Granqvist, 2010; Tegart, 2010; Thomas & Wright, 2008).

R&D activities, along with limited commercialisation activities, are occurring in Australia in each of the above categories. Most of these activities are occurring in research institutions and related programs (e.g. the Victorian Organic Solar Cell Consortium, Bionic Vision Australia consortium), with some government-supported commercialisation programs.

We believe these 'hopes', and associated capabilities, should be considered in the context of the wicked problems they are intended to help solve, as well as from futures and social perspectives. These framings also highlight commercialisation issues and opportunities.

Wicked problems and emerging technologies

A 'wicked' problem is a "complex issue that defies complete definition, for which there can be no final solution, since any resolution generates further issues, and where solutions are not true or false or good or bad, but the best that can be done at the time" (Brown, Harris, & Russell, 2010, p. 4). In contrast, 'tame' problems are readily defined by interested parties and resolution is generally unproblematic. These definition highlights that many – if not most – contemporary challenges are 'wicked' problems presenting significant new innovation and policy-making challenges. These challenges include climate change, food and energy security, productivity growth, health and demographic issues such as obesity and a rapidly ageing population, and biodiversity loss. Such problems are contested problems, for which there is consequently diverse perspectives on how they should and could be tackled. Those proposing solutions to wicked problems – such as solutions centred on the use of emerging or converging technologies – are likely to encounter very different perspectives. For example, this is seen in nanotechnology debates, with critics proposing alternative solutions to energy and climate problems, among other challenges, and raising concerns about additional future issues that nanotechnology solutions may introduce (McGrail, 2011). The concept of wicked problems also highlights the need for policymakers to consider further issues which may be created by their 'solutions'.

The concept of wicked problems has additional relevance. An authoritative review of the regulatory issues associated with nanotechnologies described regulating nanotechnology as a wicked problem (Hodge et al., 2010; Klijn, 2008). This is because the development of emerging technologies – such as nanotechnology – is often characterised by diverse stakeholders, values conflicts, and uncertainties around risks (Hodge et al., 2010; Kastenhofer, 2011). Further, as seen in genetically-modified (GM) foods debates the conflicting worldviews of proponents, opponents and other actors can generate irresolvable social conflicts (Dryzek et al., 2009).

Finally, considered together, hopes for emerging technologies represent possible 'high technology' futures which should be the subject of careful deliberation. For example, high-tech assisted ageing futures (gerontechnology) – which could entail incorporating assistive and safety technologies in housing that reduce risks of falls, fires, etc, and enable ageing-at-home, and new remote health monitoring systems – is one way of developing healthcare for Australia's ageing population. However, such technologies raise issues that will influence public acceptance and the level of adoption. These issues include perceived loss of privacy in the context of monitoring systems, and potential misuse of personal information (Tegart, 2010). Contrasting perspectives also exist, such as those favouring a 'high touch' personal care approach. Additionally, new models of healthcare service delivery need to be considered. However, such 'high technology' futures are inherently difficult to assess and govern, due to non-linear development processes and the high level of uncertainty (see Spinardi & Williams, 2005; Williams, 2006).

Evolving Contexts for Technology Development

The evolving Australian context

The policy context for emerging technologies has rapidly evolved in Australia in recent years. The Australian Government's (2009) innovation agenda, *Powering Ideas*, included a 25% increase in funding to $8.58 billion for science and innovation. A core goal is to develop 'future industries' (e.g. advanced manufacturing) that enable diversification of the economy. The *National Enabling Technologies Strategy* (NETS) was also released by the Federal Government in 2010, replacing the *National Nanotechnology Strategy* (NNS). The goals of NETS are to "maximise community confidence [i.e. address risk concerns] and community benefits from the use of new technology" (Australian Government, 2010). NETS provides $38.3 million in funding, with approximately half to be spent on metrology aspects (e.g. through the National Measurement Institute), establishing new standards and infrastructure, and the remaining budget funding activities to promote industry uptake and increase public engagement.

At the State level, in 2010 the then Victorian Brumby Government replaced its *Nanotechnology Statement* – the first State Government policy aimed at developing a nanotechnology industry and attracting investment – with an action plan for 'small technologies'. Both NETS and the Victorian Action Plan (Victorian Government, 2010) represent an important broadening of focus from a nanotechnology focus to a more diverse emerging technologies orientation. Elsewhere, such as in South Australia and Queensland, the focus of policy and industry development has mostly shifted to priority industries (e.g. therapeutic medicines, cleantech).

Additionally, the stated aim of responsible development (or 'responsible management') has become far more prominent (Australian Government, 2008a; Australian Government, 2010). This is defined as "capturing the benefits" of emerging technologies whilst "addressing health, safety and environmental concerns" (Australian Government, 2008a, p.1). Nonetheless, some environmental groups, unions and consumer groups are publicly expressing safety concerns about nanotechnologies, particularly about nano-particles in consumer products (e.g. sunscreens, antibacterial products) and potential worker health risks (e.g. ACTU, 2009; Australian Education Union, 2011; McGrail, 2011; Miller et al., 2006; Miller & Senjen, 2008).

Finally, a number of major infrastructure investments have recently been made to support work on emerging technologies. The Australian National Fabrication Facility (ANFF), established as part of the National Collaborative Research Infrastructure Strategy, now has nodes in each State such as the Melbourne Centre for NanoFabrication which operates the largest purpose-built cleanroom complex in the Southern Hemisphere. Additionally, the Australian Synchrotron provides key research and development infrastructure. Whilst these investments are important for the goal of developing frontier technologies in Australia, there are concerns about the level of usage and future funding support as the approach to nanotechnology and other emerging technologies has become more cautious and moderated (McGrail, 2011).

Broader socio-political context: The rise of Asia

Over the last decade the global science landscape has dramatically changed. China has risen to become a major player and is expected to surpass the United States as the dominant publisher of scientific research before 2020, possibly as early as 2013/4 (Royal Society, 2011). Chinese spending on scientific research has grown 20% per annum since 1999 and is now over US$100 billion a year (Royal Society, 2011). Other Asian nations, such as South Korea and India, are also rising science powers (Royal Society, 2011). Notable is the shift in cleantech investment to Asian nations such as China and South Korea (Atkinson et al., 2009). Middle Eastern countries such as Saudi Arabia and United Arab Emirates are also investing their oil wealth in large research and technology development programs (Stremlau, 2011). These trends indicate that efforts to expand 'green collar' jobs and secure associated manufacturing opportunities in Australia will encounter further competition from Asia and the Middle East. Competition to establish 'future industries', such as cleantech, has become increasingly global.

Development and adoption challenges

There are many signals the development of emerging technologies, especially nano- and bio-technologies, has been slower and more problematic than expected. These signals challenge the commonly-held view that technological change is accelerating (Jones, 2011a). For example, nanotechnology experts have pointed to various factors slowing technology development and adoption, including: increasing focus on the risk and the potential toxicity of nano-particles and nanomaterials (Bastos, 2011; Royal Commission on Environmental Pollution, 2008); emerging 'disappointment cycles' caused by realities not matching earlier predictions and the failure of commercialisation start-ups (Jones, 2011a, 2011b; McGrail, 2011); misunderstandings caused by the transdisciplinary nature of these fields (Jones, 2011b); and very high capital and institutional capacity requirements. A major issue is the creation of false expectations due, in part, to a lack of understanding of physical constraints such as the influence of different nanoscale forces (Jones, 2004, 2011a). Critiques of early nanotechnology pioneers, such as Erik Drexler, similarly argue that their visions and forecasts are scientifically flawed and therefore unrealistic.

Regulation and oversight also present challenges to nanotechnology development. Regulatory uncertainty and recent policy responses, such as the new NICNAS (National Industrial Chemicals Notification and Assessment Scheme) requirements for 'industrial nanomaterials', can impact development by reducing access to investment capital (Hoerr, 2011). Indeed, some Australian industrial players have strong concerns about uncertainties in, and changes to, the regulatory environment and indicated this is contributing to a shift away from nanotechnology (McGrail, 2011). Product labelling and marketing issues have also intensified.

The development of biotechnologies has also often been more problematic than expected. GM food controversies are the obvious example; however, concerns extend to new developments in non-food GM crops which may for example also be used for energy production (Sheppard et al., 2011). Beyond these controversies Jones (2011a) points to the "slowness of new technologies like stem cells and tissue engineering to deliver" and innovation challenges in the pharmaceutical sector. Indeed, the stem cell industry has only recently started to recover from disillusionment that followed industry collapse that occurred in early 2000s – as stakeholder relations improved, academia delivered necessary science, and regulatory changes emerged (Mason & Manzotti, 2010). Finally, genomics has also largely failed to-date to meet expectations and many consider it to be uncertain whether it will ever deliver on its promises (S.

Jones, 2009).

In the cleantech sector, investment dropped in 2008-2009, perhaps in response to the Global Financial Crisis. However, recent data suggests investment is now improving (Australian Cleantech, 2011). More importantly, recent reviews indicate that companies and activities in the Australian cleantech sector tend to be service companies, installers, etc, rather than *developers* and *manufactures* of new and emerging technologies (Alford & O'Brien, 2010).

Shaping Effective Responses to Emerging Technologies

The futures of emerging technologies clearly depend on the capacity to meet a range of key challenges – technical, social, economic, and political. Australian efforts in many domains have to-date struggled to progress. Trends indicate limited development and take-up of frontier technologies, and continuing conflict and controversy such as about GM crops (Clarke, 2011). Furthermore, these trends suggest Australia is yet to meet the key challenge, as framed by Falk (2007, p.86), of becoming "good as a nation at utilising emerging technologies to meet national goals". How should we think about and plan for the futures of emerging technologies? Are major changes to technology assessment, governance and innovation in Australia demanded? Here we isolate six key challenges and opportunities, aiming to complement existing work on these topics (e.g. the 2008 Cutler Review of Australia's National Innovation System).

Consideration of *national* choices and associated alternative futures

Emerging technologies present national communities with important choices about their future (Falk, 2007). As the OECD (2009, p.16) asserts, "achieving the full promise of the bioeconomy by 2030" would require "a policy framework that can address technological, economic and institutional challenges", with some areas of biotechnology needing "major policy interventions and new policy mechanisms" to enable their development. Such policies would need to address specific challenges in all main applications areas (i.e. health, agriculture, industry) and various cross-cutting issues such as intellectual property (Ibid). McNeil (2009) similarly argues that any realistic aspiration for Australia to build a thriving cleantech and clean energy sectors – and to potentially become a clean energy superpower – demands bolder, longer-term visions and "21st century equivalents of the Snowy Mountain Hydro-Electric Scheme". Such choices, if made, should be informed by social and community foresight. This paper also shows that present and potential future circumstances – such as the complexities of 'wicked' problems, development challenges, and increasing global competition – also need to be taken into account when forming such goals. Potential national choices, and associated futures analysis, present key challenges for both science foresight and governance. Additionally, technological 'hopes' provide articulated images of the future which can be deliberated and, potentially, planned for.

Genuinely going beyond 'science-push' and 'technology-push'

As noted earlier, contemporary emerging technologies tend to be quite *generic* in scope and have the associated tendency for technology-push. This suggests shifts are required – such as more inclusive consideration of the problems that need solving (e.g. pressing societal issues, customer needs/problems) and potential solutions – so that science and technology development can become more demand-driven. This in turn demands more open approaches, such as through end-user involvement, and sensitivity to social, economic, and ethical contexts. One opportunity is that major hopes for new technologies could be more openly debated in interactive platforms (both offline and online). Coordination around visions could also be sought. These actions help to provide a framework for 'next-wave' public and stakeholder engagement.

Expectations

Expectations about emerging technologies held by different actor groups, that is the "circulating representations of the future" (van Lente, 2011), strongly influences their development (Borup et al., 2006). Emerging technologies can often be 'self-fulfilling prophecies', and hype influences innovation trajectories. Also important are community and stakeholder expectations. A related challenge, however, is that people tend to respond to information on technologies based on their already-held views and values, rather than based primarily on a rational assessment of benefits and risks (Cormick, 2011). An opportunity is to use foresight activities to assess and modulate actor expectations, and help coordinate 'collective' expectations (Truffer et al., 2008). Whilst some foresight activities are being conducted as part of NETS through Expert Forum initiatives – such as including industry workshops and public engagement events – greater focus on assessing and modulating expectations and addressing 'expectation dynamics' is needed.

Adopting ways of thinking and planning suited to taming 'wicked' problems

Given governance of emerging technologies is an important 'wicked' problem, insights from the literature on this type of problem could be drawn on (e.g. see Australian Public Service Commission, 2007; Rayner, 2006; Roberts, 2000). One framework outlined in this literature is of egalitarian/collaborative, competitive and hierarchical/authoritative strategies (Robert, 2000). It is clear that stakeholders are advocating different approaches, with increasing evidence that expert-centred 'hierarchical/authoritative' strategies – that tend to dominate – are failing to deliver desired outcomes. *Table 3* outlines these contrasting approaches.

Table 3. *Approaches to 'wicked problems' and potential application to emerging technologies*

Approach	Framing	Application (current / potential)
Egalitarian / collaborative	Open up the problem to stakeholders, amongst whom power is dispersed.	• Stakeholder and public engagement • 'Technology democracy' i.e. public sets priorities and 'steers' technology
Competitive	Use expertise and influence to control resources brought to bear on a problem and how it is addressed.	• The peak bodies attempt to influence spending (e.g. via Academies) • Competitive research funding (e.g. ARC grants) determines technology • Market forces determining directions
Hierarchical/ authoritative	Problem-solving left to designated experts: transfer power to them and abide by their decisions (e.g. Reserve Bank determining interest rates). Apply established decision routines and decision rules (e.g. cost-benefit analysis, 'science-based policy').	• Experts adjudicate key risk issues • Formal bodies determine standards, important definitions, etc • Peak bodies and/or senior scientists given additional powers to determine scientific priorities and progress

This framework can provide ways of conceptualising different approaches and understanding conflicting perspectives. How could it be ensured that all these approaches are being effectively and equally considered? How could a variety of strategies be used for specific wicked problems, such as for risk assessment of nanotechnologies?

Further develop the emerging 'anticipatory shift'

Futures thinking naturally emerges around new and potential technologies; it is the quality of it that matters, along with its influence on technology development trajectories. As such, the recent 'anticipatory shift' in science policy and governance is important (McGrail, 2010). This shift includes: 'upstream' public and stakeholder engagement on potential future technologies; earlier debate about the potential ethical, legal and social implications of these technologies (ELSI analysis); and increased voicing of visions and promises by scientists and policy-makers. Further developing this shift presents a number of challenges and opportunities, including: confronting the 'problem of prediction' which exists when technologies are at an early stage of development and influences public and stakeholder engagement exercises (Tait, 2009); and far more explicit engagement with public values aspects (e.g. considering preferred – as well as potential – futures and how values and belief systems shape these preferences). Further, how can alternative visions be better heard and incorporated into science and technology? Can the complexity of potential consequences be better factored into research and technology development?

Broadening science stories and conversations about new technologies

Economic stories and outcomes have dominated discussion about emerging technologies (e.g. productivity, new industries, etc). These now need to be complemented by and integrated with far broader stories, which genuinely factor in the ‘triple bottom line’ (economic, environmental, social outcomes) and seek to be holistic. For example, in the context of next-generation biofuels, and potential bioeconomies there is a need to consider food security implications and biosecurity issues such as invasion threats from the introduction of new crop species (Sheppard et al., 2011; Tilman et al., 2009), as well as economic and energy security outcomes. Another example is urban futures. It is difficult to consider the potential use of new energy efficiency and generation technologies (e.g. from nanotechnologies) and future materials without considering consumer preferences, density, access to skills, regulation, and the future form of cities.

Senator Kim Carr, then Minister for Innovation, outlined the need for broadening the stories we tell, and conversations we have, around new technologies by asserting that "we can't build better cities without understanding how people want to live and how the different parts of people's lives fit together" and "we can't adapt to global warming without understanding what people's capacities are, how they interact and of course what motivates them" (quoted in Salleh, 2008). However, such stories require both a far more holistic outlook and more imagination. Fostering such an outlook and imagination is a key foresight and governance challenge.

Conclusion

The issues, challenges and opportunities outlined in this paper demonstrate that the potential role of emerging technologies in addressing contemporary Australian challenges is multi-dimensional and uncertain. Industry uptake and public acceptance are affected by the way expectations develop and are framed, alignment between technology and societal needs, and the breadth of application. Linked with this science stories, conversations and *prospective* analysis must significantly broaden if technology development is to be made more sustainable. Further, whilst progression of technology is clearly important, cultural contexts, social innovation, and behaviour change must also be incorporated into the visions and strategies the context demands.

Second, complex opportunities and challenges for foresight and governance practices mark the emerging technologies landscape. If the past is a good guide to the future then policy agendas will continue to evolve rapidly and major, often unanticipated, development challenges will be encountered. Moreover, the challenges being faced, compared with expectations, raise questions about how effective emerging technologies might be in tackling current social and environmental problems given due to the need for more rapid innovation and changes.

However, the potential levers for science and technology uptake and governance mean that the past may not be a good guide. It is difficult to assess the prospect for emerging technologies to challenge prevailing systems, practices and industries in Australia. It is even harder to anticipate all the future societal outcomes such technologies may generate. What is clear is that there is wide range of hopes for breakthroughs generated by their development and adoption. Indeed, emerging and converging technologies could play diverse roles in taming contemporary ‘wicked’ problems such as climate change and energy security; however, a wide range of complex actions are needed, such as those noted here, if they are to play these roles in the future.

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Notes

1 The 'nanoscale' is today defined as 1-100 nanometers. The prefix 'nano' which is used in 'nanotechnology' comes from the Greek word 'nanos' which means a dwarf.

2 The cited reports highlight that the concept of 'enabling' technologies has multiple meanings. Indeed, Nordmann's (2004, p.14) report for the European Commission argue 'converging' technologies' should be understood as 'enabling' technologies. Converging technologies are defined here as a group of "enabling technologies and knowledge systems that enable each other in the pursuit of a common goal" (e.g. healthier, more active, ageing). The Australian Government (2010) definition is more basic defining enabling technologies as "new technologies or new uses for existing technologies that enable new products or services or more efficient processes".

3 Genomics', the creation of new human genome-scale and based technologies, tends in contrast to focus on the potential for 'personalised medicines' (e.g. gene therapies).

4 Interested readers are also encouraged to see the recently released draft Enabling Technologies Roadmap Study which outlines the potential applications of nanotechnology, biotechnology and synthetic biology and raises these in the context of Australia's major challenges (Australian Institute for Commercialisation, 2011).

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