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Under the regulatory radar? Nanotechnologies and their impacts for rural Australia

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Abstract

Nanotechnology is the latest platform technology to capture the imagination of the agricultural and food industries, with applications being adopted across these entire sectors. With companies such as Kraft Foods and H. J. Heinz investing heavily in nanotechnology research and development, industry commentators have suggested that the global nano-agri-food sector will, by 2010, be worth in excess of US$20 billion. While the nano-revolution is well under way, however, the entry of nanotechnologies into paddocks and onto our plates has occurred largely beneath the policy and regulatory radars. As such, agricultural inputs and food items that contain nano-materials are unlabelled, thereby preventing consumers from differentiating between nano-products and their non-nano counterparts. This situation persists, despite a mounting body of scientific evidence pointing to potential health and environmental risks associated with the manufacture of, and exposure to, nano-materials.

While proponents of nanotechnology promise a range of benefits across the agri-food sector, this chapter considers the potential impact of the unfettered introduction of agriculture and food-related nanotechnologies on Australian rural communities. To date, this issue has received little recognition in the emerging debates. Our chapter contributes to these critical discussions by highlighting a range of social issues associated with the introduction of nanotechnology for rural Australia within the context of the development and application of nanotechnologies across the agri-food sector. The chapter also identifies potential human and environmental risks for these communities. We argue that a lack of nano-specific regulations could exacerbate a number of these risks.

Introduction

Nanotechnologies are a panacea for global social and environmental problems—or so industry and governments proclaim. At the same time, critics argue that nanotechnologies could present a range of new risks to human and environmental health and safety (Friends of the Earth 2006a; ETC Group 2003; International Centre for Technology Assessment 2006). Despite these conflicting views, research and development of nanotechnologies are occurring at a rapid pace, with total global investment in 2005 estimated to be worth US$9.6 billion (Lux Research Incorporated 2005). As a result, products derived from nano-techniques or containing nano-materials are already on the market, despite the absence of nano-specific regulations or labelling requirements. The agricultural and food industries are among those to have embraced nanotechnologies, with leading industry commentators suggesting that the nano-agri-food industry will be worth in excess of US$20 billion by 2010 (Helmut Kaiser 2004).

Even at this early stage, nanotechnologies are being developed for applications from paddock to the plate and promise to bring profound impacts for people and the environment. It is anticipated, for example, that within the short to medium term, farmers will have access to a new range of 'smart' inputs and products, including nano-seed varieties with in-built pesticides that will release by remote control or under specific environmental conditions (ETC Group 2003a). It is anticipated that nano-cochleates and nano-encapsulation techniques[1] will enable consumers to select foods that match their personal tastes and physiological requirements. These applications of nanotechnologies across the agri-food sector will have specific impacts for rural communities. People living in rural communities are, and will increasingly be, directly exposed to nano-agri-food applications, as food producers, residents and consumers.

Despite the potential human and environmental health and safety issues for the whole society, including rural communities, there is an absence of federal nano-specific regulations to oversee research through to the commercial application of nanotechnologies, including those relating directly to the agri-food sector (Marchant and Sylvester 2006; Bowman and Hodge 2007a). As explored in this chapter, however, nanotechnology poses a number of regulatory challenges for rural Australians—challenges that are similarly faced by rural communities globally. In this chapter, we examine the current and projected social, health and environmental impacts associated with the emerging nano-agri-food industry. It is argued that the current regulatory gaps in relation to nanotechnology have the potential to exacerbate potential risks and adverse impacts. Our chapter concludes that there is a clear need for governments, including the Australian Government, to implement nano-specific regulations, which minimise the potential adverse impacts of nanotechnology to humans and the environment, including rural communities, while also taking into account the views and concerns of citizens.

Technological change in rural Australia

There is a history of technological innovation in agriculture and agri-food production. The latest of these technological innovations include the new genetic and cellular plant and animal breeding and reproduction techniques, information and satellite technologies and the continued evolution of chemical inputs and mechanical technologies. The products of these technological innovations have been diverse: novel seed and animal varieties, new varieties of chemical pesticides, fertilisers and veterinary drugs, the ability to manage ever larger scale farming operations and the reduced dependence on farm labourers for specific tasks (Bonanno et al. 1994; Busch et al. 1991; Goodman et al. 1987). Many new technologies have been promoted with promises of increased productivity, improved efficiency, greater precision, reduced costs for industry and consumers alike, economies of scale and, ultimately, increased profitability for industry. New technologies have also been promoted by some in terms of their claimed environmental benefits, such as the reduction in the use of chemical inputs and water, alongside growing concerns about some specific environmental problems in recent years (Huang et al. 2003). In short, agri-food technological innovations have been continually proclaimed as a social and environmental panacea for rural communities.

Successive waves of technological development have been the primary drivers of change in not only the technical means and practices of production, but in the structures and cultures of production. The increasing scale of production and size of farms, the decline in the number of farm families and rural communities and the increasing control that agri-food input suppliers exercise over farmers have all been facilitated by technological innovation (Lawrence 1987; McMichael 1999). One of the characteristics of this technology-driven mode of production is the technological treadmill that farmers have been on for the past century—whereby farmers and other food producers are compelled to quickly adopt the latest tools and products of innovation to remain competitive—from the mechanical and chemical treadmills, to the genetic and information technology treadmills, and now the nano-treadmill.

While it is claimed that modern biotechnology has been to date the 'latest and perhaps most fundamental innovative technology to be applied to the agri-food sector' (Phillips 2002:504), the convergence of nanotechnology with the food and food-processing sectors is anticipated to further revolutionise agricultural production. Nanotechnology represents a new techno-scientific *platform* that will potentially facilitate technological innovation across all agricultural inputs, practices and products of the agri-food system.

Nanotechnology commonly refers to any engineered materials, structures and systems that operate at a scale of 100 nanometres or less (one nanometre is one-billionth of a metre, or 10^{-9}). At this scale, nano-materials, relative to the same material at a larger size, have significantly different chemical reactivity, electrical conductivity, strength, mobility, solubility and magnetic and optical properties (Royal Society and Royal Academy of Engineering 2004). In order to exploit these novel properties, nano-scale techniques, equipment and products are being developed and applied across a range of scientific disciplines and technological forms, including chemistry, physics, biotechnology, information technology and engineering. The production of a range of engineered nanoparticles, including tubes, dots and fullerenes, has dominated the first wave of nanotechnology applications, offering aesthetical and functional improvements to conventional products. Nanoparticles have been incorporated into a wide range of everyday products, ranging from paints and cosmetics to electronics and car tyres (Woodrow Wilson 2007). It is anticipated that this 'first generation' will be followed by second, third and fourth generations of manipulating and reconstituting materials and living organisms at the nano-scale, and the construction of objects and systems from the 'bottom up'.

Nanotechnology has captured the imagination of the agri-food sector, with leading food and agri-chemical companies such as Kraft Foods, H. J. Heinz and Syngenta all racing to get a slice of the nano-pie. Established in 2000, Kraft's global research consortium of 15 university and private laboratories, 'NanoteK', reflects the corporate drive behind the nano-agri-food sector (Kuzma and VerHage 2006; Rowan 2004). The ETC Group (2004a) reports that nanotech materials and products being researched and commercialised include seed and animal breeding applications, nano-pesticides, remote sensing and precision farming technologies, as well as food processing, packaging and retailing applications.

A commercially available example of nanotechnology being used in the agri-food sector is a new generation of chemical pesticides or 'nano-pesticides'. These include nano-scale chemical pesticide emulsions and nano-encapsulation techniques. One strategy for producing nano-pesticides is to take an existing chemical pesticide—particularly one that already has received regulatory approval for environmental release—and to reduce the size of the active molecules to the nano-scale. This reduction in scale can give the pesticide new and beneficial properties for pest control, such as increased dissolvability in water, increased stability, the capacity for absorption into plants or increased toxicity to pests. The global agribusiness company Syngenta—with global sales of more than US$8.05 billion in 2006—already retails a number of pesticides with emulsions containing nanoparticles, including Primo MAXX Plant Growth Regulator and Banner MAXX Fungicide (ETC 2004b).

In contrast, nano-encapsulation techniques are utilised to create nano-scale capsules, which are designed to transport chemical substances such as toxins. The nano-scale capsules can be designed to release in specific environmental or physiological environments, such as inside the stomach of an insect. These 'smart' pesticides could provide more precise, controlled and effective use of pesticides, and therefore potentially reduce the overall quantities of pesticide used. Nano-sensors are 'smart' nano-scale particles that are able to be engineered to provide real-time monitoring of situations and for gathering information on the nutrient levels of soils, water availability and the presence of pests and pathogens affecting plant and animal growth. Nano-sensors will provide information to computer-controlled, GPS-guided, precision-farming systems. These nano-sensors could potentially be scattered and distributed widely over farming landscapes.

Approaches to nano-regulation and its limits

As noted earlier, agri-food nanotechnologies are being promoted with promises of increased productivity, profitability and environmental sustainability. At this early stage in the development and commercialisation of nanotechnology-based products, however, considerable uncertainty exists as to the extent to which these social, economic and environmental claims will be realised, and over what timelines. Scientific uncertainty also exists over the potential hazards posed by engineered nanoparticles (Aitken et al. 2004; Oberdörster et al. 2005), with Maynard (2006:10) noting, for instance, that 'certain nanoparticles may move easily into sensitive lung tissues after inhalation, and cause damage that can lead to chronic breathing problems'. Due to these uncertainties, nanotechnologies must be regulated in such a way that ensures that the supposed benefits are not overshadowed by the potential risks (Bowman and Fitzharris 2007). Bearing this balancing act in mind, this chapter now turns to an examination of how nanotechnologies are currently regulated within Australia. This approach will be briefly compared with regulatory developments occurring elsewhere.

As stated by van Calster (2006:360), 'nanotechnology will never go "unregulated". In other words, it will never be a "lawless" technology. Ordinary principles of law will apply to nanotechnology.' Accordingly, Marchant and Sylvester (2006) and Bowman and Hodge (2007b) have pointed to a range of legislative and regulatory mechanisms for 'regulating' nanotechnology across the various stages of its life cycle, from research and development through to disposal. With the majority of these frameworks having been in existence for some time, however, leading commentators have begun to question the suitability of these regulatory frameworks in relation to nanotechnology. Bowman and Hodge (2006:1068) argue that 'while governments have invested heavily in R&D programs they have been noticeably unenthusiastic about implementing new [nano-specific] regulatory frameworks for risk minimisation'.

The increasing use of the nanotechnology label in commercially available products—resulting in increasing public curiosity about the technology, increased media coverage and greater public debate about associated risks and benefits—would appear to have played an important role in stimulating policy action within the Australian Government about the future of nanotechnology in Australia. As discussed by Bowman and Hodge (2007c), these activities are probably best illustrated by the establishment of the National Nanotechnology Strategy Taskforce (NNST) in mid 2005, in order to devise 'a national strategy for development and regulation of the emerging field of nanotechnology' (Macfarlane 2006). The public release of the NNST's report, *Options for a national nanotechnology strategy*, in September 2006 articulated a nine-point plan designed to secure Australia's future role in nanotechnology. Despite the rapidly expanding nano-agri-food industries as outlined above, the report did not address applications of nanotechnology within the agri-food sector or the specific concerns for rural communities alongside the extension of nanotechnologies across rural landscapes. While it has been suggested that the report 'will help to establish a regulatory framework for the development of nanotechnology applications' (Macfarlane 2006), the report explicitly states that 'there is currently no case for establishing any new, nanotechnology specific regulations, but rather, existing regulations may need some adjustments' (NNST 2006:32). The NNST's emphatic rejection of new, nanotechnology-specific regulations can be contrasted with regulatory approaches that have been adopted by Australian governments in respect to other, earlier 'revolutionary' advances, including genetically modified organisms (GMOs). Since 2001, dealings with GMOs have been regulated through a national regulatory scheme, the Gene Technology Regulator, in coordination with other federal regulatory agencies, and supplemented further by state and territory regulations (Ludlow 2004, 2005). As such, the development of specific regulation for new technologies in Australia is clearly not without precedent. The development of such a scheme for nanotechnology, however, could be somewhat more challenging given the potential scope of the technology.

While the NNST did not articulate which regulatory frameworks or how these current provisions could be adjusted, the Australian Government has subsequently published a request for tender for the 'review of the capacity of Australia's regulatory frameworks to manage any potential impacts of nanotechnology' (DITR 2006:4). As noted in the tender document, the focus of the review will be on the health, safety and environmental (HSE) implications of nanotechnologies for Australia in the next 10 years (DITR 2006). Importantly, it would appear that this review will not be limited to Australia's chemical regulatory framework, but will also include consideration of quarantine, agricultural and veterinary chemicals and environmental regulatory frameworks. While it is unclear whether the findings of the review will be made public, it is anticipated that the final report will provide a basis for deciding how best to govern nanotechnology within the Australian context.

Looking further afield, commentators such as Wardark (2003), Davies (2006), Kimbrell (2006) and Taylor (2006) have highlighted the limitations within existing US regulatory frameworks in relation to nanotechnologies, specifically industrial chemicals (as regulated by the Environmental Protection Agency) and cosmetics and foods (as regulated by the Food and Drug Administration). Across the Atlantic, Chaudhry et al. (2006, 2007) have observed a number of gaps in relation to a range of nanotechnology products and applications in respect to the current UK environmental regulations. As observed by Bowman and Hodge (2007b), commentators including Balbus et al. (2006) and Kimbrell (2006) have suggested that one way in which governments could easily address these gaps is through the introduction of nano-specific provisions within existing national legislation. Others believe that more is needed in order to protect human and environmental health and safety concerns. Bowman and Hodge (2007b) note, for instance, that leading non-governmental organisation Friends of the Earth (2006b) has advocated that a new, nano-specific framework is needed to address the current risks, uncertainties and complexities of nanotechnologies. Others have gone further. Since as early as 2002, the US-based Action Group on Erosion, Technology and Concentration (the ETC Group) has repeatedly called for a moratorium on the commercial production of new nano-materials until an appropriate regulatory framework is implemented (ETC Group 2002, 2003b, 2004b).

Amid these growing calls for regulatory action, in December 2006, the City of Berkeley in California took regulatory action into its own hands by amending the hazardous materials and waste management sections of its municipal code to explicitly include 'manufactured nanoparticles' under its scope (Del Vecchio 2006; Associated Press 2006a, 2006b; Monica et al. 2007). The amendments, which were reportedly in response to the city council's concerns about current occupational practices within two local laboratories, and the potentially hazardous nature of nanoparticles (Del Vecchio 2006), imposed 'comprehensive disclosure requirements on companies that manufacture or use manufactured nanoparticles within the city' (Monica et al. 2007:68). These requirements do not extend, however, to federally funded laboratories within the city's limits, including, for example, the University of California at Berkeley. While the effectiveness of these amendments is unknown at this time, it has been reported that other US cities are currently in the process of reviewing their own municipal codes in order to specifically regulate nanoparticles within their own jurisdictions (Williams 2007; Bowman and Hodge 2007b).

Agri-food nanotechnologies and their social impacts for rural Australia

While the nano-regulatory debate continues to gather momentum nationally and internationally, Australian rural communities are already engaging with agri-food nanotechnologies. Nanotechnology can be found in paddocks and on plates, exposing rural people to nanotechnologies as producers and consumers. This exposure is likely to increase as investment in agri-food nanotechnologies expands. This chapter now turns to an overview of the current and likely social impacts and the potential human and environmental risks associated with the application of nanotechnologies across agri-food industries. It is argued that there is a fundamental need for the public to be actively engaged and involved in shaping nanotechnology policy, including the development of regulatory responses to address the current limitations within Australia's regulatory frameworks.

As with previous technological innovations, the agricultural and food industries assert sweeping claims about the social benefits that will arise from nanotechnologies. Proponents present nanotechnology as a miracle cure for problems as diverse as world hunger, homelessness and protecting national security. Dunkley (2004:1131), for example, declares that through applications of nanotechnology, '[f]ood could be replicated. Starvation and hunger could be eliminated from the globe.' In a less bold approach, Roco and Bainbridge (2005:3) claim that '[n]anotechnology will help ensure that we can produce enough food by improving inventory storage and the ability to grow at high yield and a diversity of crops locally'. In the nano-agri-food sector, agricultural producers have been made a range of promises related to their uptake of nanotechnologies, including a reduction in the costs of farming and chemical use, alongside an increase in farm productivity, while the promised benefits to consumers include safer and more nutritious food (Weiss et al. 2006).

Despite the promises, there is a conspicuous gap in publicly available data to substantiate these claims. According to Sandler and Kay (2006:679), '[w]hile scientists and industry leaders may be "elite" in their knowledge of the science and business of nanotechnology, this status does not imply that they are "elite" with respect to the SEI [social and ethical issues] associated with nanotechnology'. Research into social and ethical dimensions of nanotechnologies attracts little resources from government and industry, leaving us with little understanding of these complex issues. In their evaluation of the National Nanotechnology Initiative (NNI), Sandler and Kay (2006) found 4 per cent of funding (or US$48 million) was directed towards ethical, legal and social (ELS) research, representing the minimum legal requirement for ELS research under the *21st Research and Development Act* (Public Law 108-153). They also found that social research that was funded through the NNI was directed into building public support and acceptance of nanotechnology, rather than deepening public understanding and engagement in nanotechnology debates, or directing nanotechnology applications towards the public good. This mandated funding of ELS research related to nanotechnologies within the United States could be contrasted with the current situation in Australia. For instance, while the NNST (2006:33) recognised the need to 'support HSE research in Australia and to support involvement in international HSE studies', it did not go as far as suggesting that the Federal Government allocate a specific percentage of all nanotechnology research and development funding towards such research. While there is clearly support within government to support these fundamental areas of research, any such investment in research related to these fields is more likely to occur in an ad hoc manner. Accordingly, it is difficult to understand how rural Australians—and Australians more generally—will be affected by this 'revolutionary' technology.

The Australian Government's inadequate response, including to ELS issues within the nanotechnology research agenda, is likely to limit the capacity to identify and/or address the social impacts associated with the application of agri-food nanotechnologies. The current regulatory arena related to nanotechnologies also inhibits the capacity to effectively identify the extent to which farmers are already engaging with nanotechnologies—including applications in plant and animal breeding, pesticides, precision farming and animal disease protection. While a search of patent databases might provide information related to what companies are researching and patenting, this painstaking process is time consuming and difficult.

Nanotechnologies—including pesticides, seeds and monitoring devices—are likely to exacerbate the cost of farming, by extending farmers' dependence on costly off-farm inputs. Australian farm families frequently suffer financial hardship, which is accentuated by declining terms of trade, rising oil prices and long-term drought conditions (Almas and Lawrence 2003). The extension of nanotechnologies into the agri-input sector has the potential to exacerbate some farmers' financial burden. While early adopters of nanotechnologies might experience a reduction in farming costs, other farmers could suffer increased costs—in the form of new inputs and technologies. While smaller producers might struggle to manage these increased input costs, leading multinational agri-chemical companies such as Syngenta, which has positioned itself at the forefront of nanotechnology research and development, appear to have already begun reaping the profits from the burgeoning nano-agri-food industry. For instance, while current regulatory frameworks do not recognise reformulated nano-pesticides as 'new' products for the purposes of risk evaluation, it would appear that national intellectual property regimes might consider such products as 'new' for the purposes of patent production. The ETC Group (2004a) has argued, for instance, that the reformulation of a product to nano-scale could enable a company to extend the patent protection period for the pesticide, thereby providing the company with exclusive rights over the product for up to another 20 years. In short, the uptake of agri-food nanotechnologies is set to concentrate economic power among corporate actors in the agri-food industry, while providing new financial burdens for farm families (Scrinis and Lyons 2007).

At the same time, the uptake of nano-agri-inputs—including pesticides and seeds produced via the convergence of nanotechnologies and genetic engineering[2] —appears destined to further entrench chemical and genetic systems of agriculture. The nano-treadmill reduces the options for low-input (cost-neutral) and organic farming systems. At the farm level, the application of nanotechnologies will appropriate space that could otherwise be cultivated utilising low external input or organic farming techniques. Farmers could be constrained from adopting low-input or organic farming by a range of controls, including patents and licensing fees that could lock them into using nanotechnologies. This could be similar to genetic engineering (GE), in which intellectual property rights have locked many farmers into the purchase of GE seeds each planting season, rather than relying on traditional seed-saving techniques. In addition, intellectual property rights require farmers to ensure they do not 'illegally' obtain privately owned GE—and now nano—material through pollen drift, cross-species transfer, and so on; while in terms of research, investment in nano-agri-food applications will likely occur at the expense of research into alternative—low-cost and low-input—farming systems (see Jones 2004).

Ownership of nano-agri-inputs by the corporate sector is also privatising new forms of agricultural and farming knowledge. Nanotechnologies will enable corporate actors to hold and control new forms of specialist knowledge, including capabilities to detect pH levels, moisture, pests and disease. This could in turn displace farmers' traditional knowledge and techniques (Miller and Kinnear 2007). At the same time that nanotechnologies could marginalise farmers' knowledge and skills, the transformation of farm work through the uptake of nano-agri-inputs could also reduce the importance of farmers and farm workers (Crow and Sarewitz 2001). For example, the integration of nanotechnology with information technology and geographical positioning systems could enable farm management to occur off-site. The ETC Group claims that such technologies will transform the farm into 'a wide area bio-factory that can be monitored and managed from a laptop' (ETC Group 2004a:8). For example, precision-farming technologies—such as seeds with inbuilt pesticides—could be released via remote control when remote nano-sensors detect pest infestation. This is likely to transform the nature of farm work and, with it, the identity of Australian farmers and farm workers.

The application of nanotechnologies to the Australian agri-food sector is also likely to pose challenges for farmers wishing to access the international market. The lack of nano-specific regulations across the world at this stage means that there are no additional constraints on domestic and international trade of agricultural goods produced using nanotechnologies. This situation could change, however, if and when national governments amend their current regulatory frameworks to specifically address nanotechnologies. As the first wave of nano-specific amendments to regulatory frameworks are likely to occur at the national level, rather than at the regional or international levels—despite harmonisation efforts by a number of multilateral bodies—Australian producers wishing to export their agricultural products could be required to conform to a number of different regulatory standards in order to access different markets. This could bring additional costs and bureaucratic procedures for Australian farmers wishing to export.

Consumer concerns regarding the potential risks could be of equal concern to Australian producers of nano-based agricultural goods. Fears in relation to GM foods within, for example, the European Union had a devastating effect on the sector (Bauer and Gaskell 2002). While public awareness of nanotechnology remains limited in Australia, the European Union and the United States (see, for example, Market Attitudes Research Services 2004; Mee et al. 2004; Gaskell et al. 2006; Cobb and Macoubrie 2004; Woodrow Wilson 2006), the prospects of a backlash against nano-foods would appear to be minimal at the present time. As consumers become increasingly knowledgeable about the technology, however, or if a nano-food scare makes its way to the front pages of the daily newspapers, the prospect of a consumer backlash is likely to increase. These market and consumer issues exacerbate economic vulnerability in rural communities.

Human health risks from nanotechnologies

Nanotechnology applications in the agri-food sector could also give rise to a number of potential health problems for rural communities in their roles as agricultural producers, as rural residents and as food consumers. To begin, people living and working in rural communities will be exposed to engineered nanoparticles—including in the form of nano-pesticides and nano-sensors. These could pose a number of health risks for rural communities. The combination of nano-pesticides and nano-seeds in rural landscapes further extends the unpredictability of adverse health impacts. The Royal Society and Royal Academy of Engineering (2004) has warned of the potential human health risks of nano-toxicity. Reflecting these concerns, the International Union of Food, Farm and Hotel Workers has called for a moratorium on nanotechnology until the effects of human exposure to nano-materials are more thoroughly understood (Friends of the Earth 2007).

Nanotechnology applications in the agri-food sector could also pose social and health problems for rural communities in their role as food consumers. As previously stated, the current lack of nano-specific regulations or labelling requirements for food containing nano-ingredients enables producers of foods to replace conventional ingredients in commercial food products with nano-scale ingredients without triggering regulatory oversight. This poses a plethora of questions relating to the potential health risks of ingesting nano-materials (see, for instance, Swiss Re 2004). We know an Australian bakery currently selling a loaf of bread that contains nano-capsules of Omega 3 that are derived from tuna-fish oil, which is marketed as 'Tip Top Up'. The fish oil is encapsulated in a tasteless calcium and soybean lipid matrix that is made available only when the nano-capsules reach the stomach (Tip Top n.d.). Food industries argue that nano-capsules will improve the delivery of nutrients in processed foods (Kuzma and VerHage 2006). Similarly, the application of nano-cochleates could enable the release of encapsulated nutrients in targeted and specific ways, in response to individual consumers' needs (Gardener 2002). Proponents of these technologies argue that nano-capsules and nano-cochleates will increase the nutrient density of foods and the match between people's nutrient requirements (for example, for calcium or iron) and food consumption. Despite the claims, such novel foods could present a range of health risks to food consumers, the majority of which researchers are only beginning to examine (Rooker 2006). While it is widely accepted that materials behave differently and express different character traits at the nano-scale, experts disagree about what this means for exposure or ingestion of nano-materials.

As previously stated, the current lack of nano-specific labelling requirements for food that contains nano-scale ingredients has ensured that the number, or indeed identity, of commercially available nano-foods in Australia and elsewhere remains unknown. For consumers, the lack of mandatory labelling has ensured that consumers are unable to identify food derived from nanotechnologies and prevents the exercise of informed choice about the food that they consume. Despite the obvious difficulties therefore in predicting this figure, the Helmut Kaiser Consultancy Group reported that, by 2005, there were already more than 300 nano-food products in the international food market, and that sales of nano-food and packaging were valued at US$5.3 billion. The consultants anticipate that this figure will rise to US$20.4 billion by 2010, alongside the expansion of the nano-food industry.

The environmental impacts of nanotechnological innovation for rural Australia

Alongside the social and potential health issues detailed above, there is a range of environmental issues and concerns associated with expanding nanotech innovation across the agri-food sector.

With the escalating and imminent problems associated with climate change, drought and declining water availability, as well as soil erosion and salinity problems, the need to transform the ecological relations of agricultural production has never been more pressing. In this context, nanotech applications and products are being strongly promoted on the basis of their environmental benefits and as enabling the shift to environmentally sustainable forms of production and consumption. In the agricultural sector, the general promise is for the development of more efficient, precise, flexible and adaptable systems of food production that will enable a more efficient and reduced use of chemicals, water and energy inputs.

Proponents of nano-agricultural innovations state the application of nanotechnologies will enable agricultural production to adapt to changing environmental and resource conditions. Proponents promise more efficient and safer chemical pesticides and fertilisers, and overall a more efficient and productive system that will minimise the use of pesticides, fertiliser and water inputs, including the more targeted use of chemical inputs, thereby reducing chemical pollution of the environment. These outcomes could be achieved by the introduction of 'smart' nano-pesticides able to be released in more controlled and precise ways; nano-sensors able to detect and inform a precise response to changing soil, water and pest conditions; and crops better adapted to particular environments. Among these high-tech visions of a smart, lean, green and efficient nano-industrial agricultural system, there has been little acknowledgment of or debate about the prospect of any specifically new environmental hazards that nano-agricultural innovations pose.

In considering the environmental implications of nanotech innovations in agricultural production, a distinction can be drawn between the impact on existing environmental problems on the one hand, and the possible introduction of a new range of environmental problems on the other. In terms of existing environmental issues, problems and dynamics—such as pollution from chemical pesticides and fertilisers, high water usage, soil degradation and diminishing biodiversity—the question is whether nanotechnology will exacerbate or alleviate some of these agro-ecological problems. Here we need to consider the case-by-case impacts of each innovation. There is, however, also the broader question of the type of agricultural production that nanotech innovation is likely to be used to support, and what are the environmental consequences of maintaining and entrenching this type of production. At the same time, nanotechnology potentially introduces an entirely new set of environmental hazards and risks, including the prospect of an entirely new form of environmental pollution: nano-pollution. In particular, there are immediate concerns relating to the release of nano-scale particles into the environment, such as nano-pesticides and nano-sensors, as well as concerns about the release of nano-engineered living organisms into the environment.

In the case of nano-pesticides, it is the very small scale of these nano-pesticidal compounds, in conjunction with a number of other physiochemical parameters including shape, particle size, crystalline structure and surface chemistry, that poses potentially greater toxicity and eco-toxicity risks in comparison with conventional chemical pesticides. The increased toxicity of some nano-scale toxins could mean greater harm not only to pests, but to all other living organisms—animals and humans. The ability for these nano-scale particles to penetrate the surface of plants could mean that pesticides also penetrate edible parts of the crop. Their size and dissolvability could mean that they contaminate soils and waterways across a wide area or travel into and affect other food chains.

Encapsulated pesticides could similarly be washed away and release their toxins in other environments, or even in the stomachs of other living organisms.

Despite concerns about the potential risks of nano-pesticides, the reformulation of a previously approved pesticide through the nano-sizing of active ingredients is likely to be considered by the regulator as an 'existing' product for the purposes of the regulatory framework. As such, despite the new properties exhibited by the nano-pesticide when compared with its conventional counterpart, the nano-pesticide will not have to be evaluated by a regulatory body on the basis of potential risks before it may be imported or manufactured in Australia.

Nano-pesticides are one of a number of new strategies being used to address the problems of the declining efficacy of older-style chemical pesticides, combined with the inevitable rising price of petrochemical-based inputs. Genetically engineered, insecticide-producing crops (that is, *Bt* crops) and genetically engineered herbicide-tolerant crops are other responses that have been implemented to create more precise and efficient forms of pesticide delivery. All these strategies maintain and entrench the toxic chemical approach to the control of insects, pathogens and weeds. Any efficiency gains and reductions in overall chemical usage will be portrayed as bringing environmental benefits, but they can equally be understood as providing ideological legitimation for the continuation of chemically dependent farming systems.

The large-scale release of nanoparticle-sized nano-sensors also raises a number of environmental concerns. Will they be biodegradable? What are the consequences of having these nano-sensors washed into soils, waterways and throughout the food chain? Their small scale means they could penetrate deeply into materials or living organisms.. There are also unlikely to be any regulations covering the release of these nano-sensors on the farm, since they would not fall under the banner, for example, of chemical inputs or novel living organisms.

Given that nano-sensors are likely to primarily support the growth of very large-scale, capital-intensive and chemical-intensive farming operations—usually at the expense of smaller-scale operations—we also need to ask what the long-term environmental implications of these technology-facilitated structural changes might be.

Conclusion: developing a nano-regulatory agenda that engages with social, health and environmental issues

Nanotechnologies are being applied across the entire agri-food system. From remote nano-sensors and nano-seeds at the farm gate, to nano-packaging and nano-'super' foods on supermarket shelves and kitchen tables, nanotechnologies have captured the imagination of the agricultural and food industries. Many of these applications have already found their way onto the market. The scale of investment from the agri-food industries suggests the variety and quantity of nano-food products is set to expand rapidly in the next few years.

The overview of current approaches to the regulation of nanotechnology-based products and applications within the agri-food sector highlights how many commercial nanotech applications are falling beneath Australia's regulatory radar, and as such, are not adequately covered by the current regulatory frameworks. The patchwork of non-nano-specific regulations covers some products and processes to varying degrees, but clear gaps within these regimes have already emerged. As such, it is reasonable to conclude that there is a lack of rigorous review before the commercialisation of some nano-products within the agri-food sector, enabling agri-food nanotechnologies to enter the market untested and unlabelled.

The limits of current approaches to nano-regulation prohibit effective monitoring and mitigation of the potential health and environmental impacts of nanotechnologies. Our chapter demonstrates a diversity of social, health and environmental risks associated with agri-food nanotechnologies. The health and safety risks are particularly acute for rural Australians, due to their multiple roles as food producers, rural residents and food consumers. People living and working in rural communities will be, for example, directly exposed to engineered nanoparticles of which little is known about their potential toxicological effects. At the same time, nanotechnologies could give rise to new eco-toxicological effects within rural environments, posing new threats to the health of soils and water, as well as biodiversity. Rural Australians also face health risks in their role as food consumers—through the ingestion of nano-foods and food stored in new nanotechnologies (for example, nano-packaging, nano-fridges, and so on).

Looking more broadly at the social issues, nanotechnology is likely to impact on many rural producers due to the likely increased costs of purchasing such inputs. Farmers who adopt nano-seeds, nano-pesticides and other technologies also face the likelihood that their produce will be rejected in some markets, similar to the bans imposed on genetically engineered foodstuffs.

Governments and industry are currently portraying agricultural nanotechnologies as environmentally and socially responsible farming technologies, suggesting that they will bring financial benefits to the farming community. It is likely some farmers will choose to adopt nanotechnologies as part of their farming practices on these grounds, despite the potential health and environmental risks and the broader societal issues associated with nanotechnology. The current patchwork of non-nano-specific regulations, however, appears to be ill equipped to grapple with the complex and challenging array of health and environmental risks presented by nanotechnologies, along with the broader societal considerations raised by the technology.

Australian and other federal governments must begin the process of playing regulatory catch-up in order to protect the health and safety of their citizens, including those within the agri-food sectors. This might involve the revision of current regulatory frameworks, with consideration given to the new complexities and challenges posed by the nanotechnologies, or the formation of a new nano-specific regulatory framework. Revision of nanotechnology regulation will be required to ensure rural communities do not carry a disproportionate level of risk associated with the emerging agri-food nano-industries.

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Endnotes

[1] Nano-cochleates or nano-encapsulation techniques are 'envelopes' that act as vehicles for the targeted delivery of micro-nutrients (including omega-3, antioxidants and polyunsaturated fatty acids). Nano-capsules 'protect' the active ingredient(s) inside and enable the controlled delivery of active ingredients under certain conditions (ETC Group 2004a; Weiss et al. 2006).

[2] Nanotechnology is an enabling technology for genetic engineering and other plant and animal breeding techniques. Nano-biotechnology refers to the intersection of nano-techniques and genetic and cellular-level techniques for the purposes of modifying living organisms. The use of nanotechnology to facilitate the breeding of new varieties of crops and animals is still in its infancy, and there is little information readily available about the kinds of research and development being undertaken.