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Chapter 16

Nanotechnology and the Techno-Corporate Agri-Food Paradigm

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Introduction

Technological innovations have played a significant role in shaping and transforming the products, production practices and socio-economic structures of agri-food systems over the past century. From the adoption of mechanical harvesters to new hybrid seed varieties, technological innovations have been associated with profound social, economic and environmental change. Over the past two decades, technoscientific innovations have also been at the heart of many controversies, crises and political struggles across the food system – including struggles over genetically modified (GM) foods, genetic erosion and contamination, the factory farming and cloning of animals, chemical pollution, the public health impacts of processed foods, the ‘food miles’ associated with the long-distance transportation of fresh and packaged foods, the corporate control of farmers and markets, and food scares such as ‘mad cow’ disease.

Nanotechnology represents the most recent and most powerful set of technologies being applied across the food system. A new range of nano-scale techniques, materials and products are currently being developed and are at the early stages of research and commercialization across all agri-food sectors, including agricultural production, food manufacturing, food packaging and retailing.

Nanotechnology generally refers to a range of techniques for directly manipulating materials, organisms and systems at a scale of 100 nanometres or less – one nanometer being one billionth of a metre. Nanotechnologies provide new and more powerful means to engage with, manipulate, and control nature and materials at the level of atoms, molecules, genes, cells and bits of information – what we refer to as the ‘nano-atomic level of engagement with nature’. Nanotechnology can be

understood not so much as a separate and distinct techno-scientific field, but rather as a new techno-scientific platform, whereby a range of existing disciplines – such as molecular biotechnology, chemistry, materials science and information technologies – are able to shift their focus down to the molecular level (ETC Group, 2003). Within the food system, this is achieved via the development of nano-chemical technologies, nano-biotechnologies and nano-information technologies.

These technologies are promoted as offering a range of benefits across the agri-food system, including productivity and efficiency gains, environmental benefits such as reduced chemical usage and adaptation to changing ecological conditions, and more nutritious and safe foods. In so doing, nanotechnologies – like other recent technological revolutions and innovations, such as genetic engineering – are being positioned as a necessary ‘techno-fix’ to the crises facing global food production (such as the need to feed a growing population) whilst also meeting the challenges of climate change and other forms of ecological degradation (Hinsliff, 2009). Yet, presenting nanotechnologies as offering narrowly framed technical advances and benefits ignores the substantive role that technologies also play in shaping, maintaining, and transforming the existing structures, cultures and ecologies of food production and consumption.

Nano-scale technologies are currently being developed within — and are primarily being used to entrench and extend – the dominant paradigms of agri-food production, distribution and consumption, and their associated technological and economic structures. In the agricultural sector, nano-industrial forms of production will extend and deepen the chemical-industrial and genetic-industrial agricultural paradigms. In food manufacturing, nano-processing techniques will facilitate the further development of processed-reconstituted foods, as well as of a new range of nutritionally engineered or ‘functional foods’. In doing so they will expand the nutritionally-reductive paradigm of ‘nutritionism’ upon which the scientific legitimacy and marketing claims of these food products are based (Scrinis, 2008a). Nano-packaging and identification innovations will also be used to facilitate the long-distance transportation, long shelf-life, supply-chain tracking, and monitoring of the food supply – all of which could support an increasingly globalized, export-oriented, and supermarket-dominated food system.

While these technologies are being developed and applied within particular agri-food paradigms, they may also directly change the form of the structural, cultural

and ecological relations they mediate by such means as: transforming production practices; changing our understanding of food and nutrition; transforming our relationship to nature; and extending the reach of commodification practices, intellectual property rights and corporate power.

This chapter outlines a range of nanotechnological applications across the agri-food sector and examines the ways these might extend or transform the existing practices, relations and structures of the food system. We also consider how the emerging regulatory regime – together with emerging civil society and consumer opposition, and competing corporate and sectoral interests – might shape or impede the development and trajectory of nanotechnological innovations.

Nano-industrial agriculture

In the agricultural sector, nanotechnological innovations are being researched and applied in the areas of plant and animal breeding, chemical pesticides, veterinary medicines and satellite-mediated ‘precision farming’ systems. These nano-industrial applications will largely be geared towards both the fine-tuning, and the creation of, new efficiencies and capabilities within large-scale, monocultural, chemical and capital-intensive styles of farming – as well as offering short-term bandaid solutions to emerging agro-ecological problems. At the same time, they may facilitate further corporate concentration of, and control over, agricultural inputs and producers. This emerging *nano-industrial* or *nano-corporate* paradigm of agricultural production has strong continuities with – and indeed is likely to frame and encapsulate – the genetic-industrial paradigm associated with the introduction of GM crops since the 1990s (Scrinis, 2007).

One of the first nano-industrial applications is the development of nano-chemical pesticides – or nano-pesticides – which are pesticides that contain nano-scale chemical toxins. Nano-scale formulations of new and existing pesticidal toxins offer a range of novel properties, such as increased toxicity, stability or dissolvability in water as compared to larger-scale molecules of the same chemical toxins. At the same time, the nano-encapsulation of pesticidal toxins offers new possibilities for the controlled or targeted release of pesticides, such as in the alkaline environment of certain insects’ digestive systems, or under specific moisture and heat levels (ETC, 2004; Kuzma, 2006; FOE, 2008). The increased toxicity of nano-pesticides and the

ability to more precisely control the quantities and conditions under which pesticides are released could result in a reduction in the volume of chemical pesticides being applied in specific situations, thereby reducing input costs and environmental pollution (Kuzma, 2006). However, nano-pesticides – like GM herbicide-tolerant and *Bt*-insecticidal crops – could also further entrench and extend the chemical approach to pest control by exploiting these new efficiencies and the expanded range of options for pesticidal delivery they offer. Nano-scale pesticides also introduce a new range of possible health and environmental hazards due to their increased toxicity and their ability to penetrate the surface of food crops. Their enhanced dissolvability may lead to the contamination of wider geographical areas. Encapsulated toxins may also be released in the gut of non-target living organisms. While such nano-pesticides may already be commercially available, there is presently an absence of labeling or public disclosure requirements for nano-scale chemicals (Bowman and Hodge, 2007).

Nano-scale wireless sensors are another industrial innovation, being developed to assist in the real-time monitoring of crops, animals and soils. Nano-sensors could detect the presence of plant pathogens and may be used to trigger the release of pesticides. These nano-sensors would form a part of so-called ‘precision farming’ systems, involving the use of information technologies and geographical positioning systems to more precisely micro-manage the application of pesticides, fertilizers and irrigation systems. It is large-scale, capital-intensive, farms that are likely to be able to adopt and benefit from the potential cost-savings, efficiencies and productivity gains of these integrated technological packages.

There is also a range of nanotechnological innovations being developed specifically for animal production systems. They include the use of micro- and nano-fluidic systems for the mass production of embryos for breeding; drug delivery systems able to penetrate inaccessible parts of an animal’s body; more biologically active drug compounds; and sensors for monitoring livestock health and locations (ETC Group, 2004; Ajmone Marsan et al, 2007; Scott, 2007). Australian researchers are developing needle-free nanoparticle vaccine delivery systems enabling the more targeted and effective vaccination of cattle, the magnetic properties of which would simultaneously enable the surveillance of treated animals (Mittar, 2008). In fish-farming operations, developments include nano-scale water cleaning products, along with nanocapsulated vaccines that would be released into the water, absorbed into the cells of the fish, and activated using ultrasound (ETC Group, 2004). In the context of

large-scale, intensive, factory-farming or close-confinement livestock operations, such innovations offer efficiency and productivity gains, together with the further adaptation or re-engineering of animals to the requirements of this mode of animal production.

The convergence and integration of nanotechnologies and biotechnologies offer new avenues for plant and animal breeding, including new techniques for facilitating the development of genetically engineered crops. For example, researchers are attempting to use nanoparticles, nanofibres and nanocapsules to introduce foreign DNA and chemicals into cells (FoE, 2008). The emerging field of synthetic biology promises a more radical approach to genetic engineering and plant breeding (ETC Group, 2007; Ribeiro and Shand, 2008). Rather than just cutting and pasting genes from one existing genome into another, bioscientists are developing a number of strategies for synthesizing novel living organisms, including the engineering of synthetic DNA. These advances in plant breeding techniques could enable the introduction and control of a wider range of genes and character traits into crops – including drought-tolerant and ‘climate-ready’ genes (ETC Group, 2008). The seed-chemical corporations that currently control the global market for genetically modified crops have also shown great interest in developing traits such as the ability to control the reproductive capabilities of seeds and to link the expression of crop traits to external chemical triggers. Nano-genetically engineered seeds could, thereby, facilitate the further technological and corporate integration of seed, chemical and other agricultural inputs.

Nano-industrial food processing and nano-engineered functional foods

In the food manufacturing sector, the development of a new range of processing techniques and additives is underway which variously aim to modify food flavour and texture, speed of processing, heat tolerance, shelf-life, nutritional profile and nutrient bioavailability. These ‘nano-engineering’ applications are likely to support the continued development of a growing range of cheap, processed and convenience foods. But it is the engineering of supposedly healthier ‘functional foods’ that are the most common examples given to illustrate the benefits of nano-food innovation (Moraru et al, 2007). The development and marketing of these nano-functional food products are framed within – and are likely to extend and transform – the nutritionally

reductive paradigm of ‘nutritionism’ that currently dominates scientific and popular understandings of the relationship between food and bodily health (Scrinis, 2008a).

As Sanguansri and Augustin (2006, p547) note, ‘The next wave of food innovation will ... require a shift from macroscopic properties to those on the meso- and nano-scales, as these subsequently control the hierarchical structures in food and food functionality’. Nanotechnology will not only extend the ability of food technologists to fractionate foods down to their nano-scale component parts, but will also provide new techniques for the reconstitution and transformation of these individual food components, before being reassembled to form ‘processed-reconstituted’ foods.

One of the broad aims of these innovations will be to achieve productivity gains and cost savings in the production of relatively cheap, processed and convenience foods. For example, a German company, Aquanova, has developed nano-sized food additives that accelerate the processing of industrial sausage and cured meats (FoE, 2008). The development of nano-scale formulations of existing flavour or nutrient additives may also enable a reduction in the quantities – and therefore the costs – of these additives, whilst achieving the same processing functionalities.

Nanotechnology also enables the introduction of new qualities and character traits into foods and food ingredients. Nano-structured food ingredients and nanoparticles in emulsions, for example, are being developed in an attempt to control the material properties of foodstuffs. Their application such as in the manufacture of ice cream to increase texture uniformity is a case in point (Rowman, 2004). The development of food ingredients able to reproduce the creamy taste and texture of full-fat dairy products would enable the production of very low-fat ice cream, mayonnaise and spreads (see Chaudhry et al, 2008). In addition, Unilever has reported breakthroughs in the development of stable liquid foams that may improve the physical and sensory properties of food products, as well as the ability to aerate products that currently do not contain air (Daniells, 2008). This aeration is also seen as a means of reducing the caloric density of foods. The food company Blue Pacific Flavors has developed its *Taste Nanology* process for engineering ingredients with more concentrated flavours by targeting specific taste receptors, making it possible to remove the bitter taste of some additives and to reduce the quantities of additives required (Anon, 2006).

In another set of applications, nano-encapsulation techniques are being developed as part of a strategy to harness the controlled delivery of nutrients and other components in processed foods. The aim is to enhance a number of functionalities, such as to ‘provide protective barriers, flavour and taste masking, controlled release and better dispersability for water-insoluble food ingredients and additives’ (Chaudhry et al, 2008, p244). Nanocapsules have been produced through the development of self-assembled nanotubes using hydrolyzed milk proteins (Chaudhry et al, 2008). Food companies are already utilising micro-capsules for delivering food components such as omega 3-rich fish oil, while masking the taste and odour of the fish oil. These nano-encapsulated fish oils are being developed as a means of enhancing the bioavailability, stability and transparency of food components (Zimet and Livney, 2009). A recent study claimed that the encapsulation of curcumin – the phytochemical found in turmeric and claimed to have antitumor and anticarcinogenic properties – in nanoemulsions increased the bioavailability of this compound (Wang, 2007). A nanococheate nutrient delivery system has also been developed and is claimed to ‘protect micronutrients and antioxidants from degradation during manufacturing and storage’ (Chaudhry et al, 2008, p244).

Nanotechnology also holds out the more distant promise of nutritionally interactive foods able to change their nutritional profile in response to an individual’s allergies, dietary needs or food preferences (FoE, 2008). Chen and Shahidi (2006, p36) describe this promise of personalized nutrition, which is based on the development of targeted delivery systems:

... advances in nanotechnology may lead to multifunctional nanoscale nutraceutical delivery systems that can simultaneously detect and recognize the appropriate location, analyze the local and global needs, decide whether or how much of the payload should be released and monitor the response for feedback.

Such futuristic applications not only assume the ability to precisely understand and manipulate the nutrient properties of foods and their effects on particular bodily functions, but also to target and address the precise nutrient needs of individuals.

Nanotechnology, thereby, provides a range of approaches to the cost effective production of so-called ‘functional foods’, or foods with modified nutrient profiles

and novel traits – foods that might be more accurately termed ‘nutritionally-engineered foods’ or ‘functionally-marketed foods’ (Scrinis, 2008b). Yet, there is reason to question the individual and public health benefits of these nutritional modifications. Like all ‘functional foods’, the claimed health benefits of nutritionally engineered nano-foods are based on a nutritionally-reductive and decontextualized understanding of food and nutrients and their relationship to bodily health. This dominant ideology or paradigm of ‘nutritionism’ typically involves the reduction of our understanding of food to its nutrient composition, such that it tends to replace and undermine other ways of understanding food and the body (Scrinis, 2008a). This often takes the form of a more simplified focus on single nutrients. Nutritionally reductive scientific knowledge has been translated into reductive dietary advice, as well as being translated directly into *nutritionally reductive technological practices*, whereby the nutrient profile of foods are engineered to reflect the nutritional trends and fetishes of the day. The efficacy of these nutritional modifications assumes not only that these single nutrients can be manipulated individually, but also that they can deliver health benefits in isolation from the foods themselves and the nutrient matrix in which they are contained (Jacobs and Tapsell, 2007).

The marketing of these nutrient content and health benefit claims is also typically focused on the single nutrients added or subtracted, thereby distracting attention from the overall nutrient profile and quality of the foods. A focus on the link between nutrients, foods and internal bodily functions, such as cholesterol absorption or blood sugar levels, is now increasingly common in popular dietary advice and food marketing campaigns. Nano-functional food innovations will provide new avenues for the production of these ‘functional’ foods intended to target particular bodily functions. These nano-engineered foods will thereby reinforce the shift to this latest ‘functional’ stage or era of nutritionism, opening up new possibilities for the commodification of nutrients, nutritional knowledge and food products.

The introduction of nano-scale components in foods also raises novel health concerns, particularly in terms of their toxicity. For example, as Pustzai and Bardocz (2006) note in their review of the health risks of nanoscale food components, nanoparticle versions of the food additives titanium oxide and silicon dioxide are already being used in foods and have been approved as GRAS (Generally Recognized As Safe) by the US Food and Drug Administration. Yet, they argue that there is already sufficient scientific evidence to indicate that these nanoparticles are cytotoxic

(that is, toxic to cells), and that their incorporation into foods has occurred without appropriate safety testing.

Nano food packaging and supply chain monitoring

The most advanced sector of nano-food innovations has been in the development and commercialization of food packaging applications, with up to five hundred nano-packaging products already on the market (FoE, 2008) Nano-engineered food packaging materials aim to better control the conditions in which fresh and prepared foods are contained so as to reduce the rate of food spoilage and to enhance its durability, transportability, shelf-life and ‘freshness’. In these ways, nano packaging innovations could facilitate an increase in the use of food packaging, enabling an expansion of the range of packaged foods, the distances these foods are transported and the time and range of conditions under which they are able to be both transported and preserved (FoE, 2008).

Some nano packaging materials are designed to reduce gas and moisture exchange and UV light exposure, or to emit antimicrobials and antioxidants, with the goal of keeping food ‘fresher’ for longer – or at least slowing deterioration. Commercial examples include the use of nanocomposite barrier technology by Miller Brewing to create plastic beer bottles. The plastic contains nanoparticles that provide a strong barrier between carbon dioxide and oxygen, which enables beer to retain its effervescence (and shelf-life) for longer (ETC Group, 2004). DuPont have also produced a nano titanium dioxide plastic additive – *DuPont Light Stabilizer 210*. By reducing UV exposure, DuPont claim that their barrier technology will minimize the damage to food contained in transparent packaging (El Amin, 2007). Nano-packaging materials are also being developed to interact with the foods they contain, such as the ability to ‘release nanoscale antimicrobials, antioxidants, flavours, fragrances or nutraceuticals into the food or beverage to extend its shelf life or to improve its taste or smell’ (FoE, 2008, p16).

This interactive, chemical-release packaging is being developed to respond to specific trigger events. For example, packaging may contain nanosensors that are engineered to change colour if a food is beginning to spoil, or if it has been contaminated by pathogens. To do this, electronic ‘noses’ and ‘tongues’ will be designed to mimic human sensory capacities, enabling them to ‘taste’ or ‘smell’

scents and flavours (ETC, 2004). In Scotland, UV activated nano titanium dioxide is being utilized to develop tamper-proof packaging materials, while in the United States carbon nanotubes are being incorporated into packaging materials to detect micro-organisms, toxic proteins and food spoilage (El Amin, 2007).

Nano-scale barcodes and monitoring devices are also being developed and commercialized. This includes nano-scale radio frequency identification tags (RFid) able to track containers or individual food items. These RFid tags could also transmit information after a product leaves the supermarket, unless the tags are disabled at the checkout register (ETC Group, 2004). The nanotech company pSiNutria is also developing nano-based tracking technologies, including an ingestible BioSilicon which could be placed in foods for monitoring purposes, but could also be eaten by consumers (FoE, 2008). Supermarkets would use nanosensors to monitor product sales and expiry dates, thus reducing the lead time for product re-ordering (Kuzma and VerHage, 2006). Nanosensors may thereby improve management efficiency for those large-scale retailers able to absorb the costs of nano monitoring and identification techniques.

The use of nanomaterials in food packaging poses a number of potential new health and environmental hazards. Nanomaterials in food packaging and food contact materials may unintentionally migrate from the packaging and into foods and thereby increase the likelihood of nanomaterial ingestion (Chaudhry et al, 2008; FoE, 2008). Active and chemical-release packaging and food contact materials designed to deliberately release substances such as flavours, odours or nutritional additives raise similar concerns. Nanomaterials in food packaging may also be released into the environment, posing a range of ecological hazards (FoE, 2008).

Techno-ecological transformations: From an instrumental to a reconstitutive logic of control

While there is a diverse range of applications of nanotechnological applications within and across all sectors of the agri-food system, a number of common characteristics or rationalities can be identified. These technological characteristics may directly or indirectly shape, extend and transform the ecological and socio-economic relations, practices and structures that they mediate.

Nanotechnologies introduce a greatly enhanced ability to manipulate and reconstitute nature at the nano-atomic level. Nanotechnology enables the deconstitution of nature and systems down to their component atoms, molecules, genes, bits, cells and other parts; the transformation or rearrangement of these component parts; and the reconstruction or reconstitution of organisms, materials and devices from the ground up. These reconstitutive practices go beyond the instrumental control, use and exploitation of whole objects of nature, and also beyond the fragmentation of nature and food into their component parts, for they also enable the further transformation and re-engineering of these parts in order to achieve specific ends.

In being reconstituted in these ways, nature is not simply encountered as raw material to be used as an input to the production process, nor encountered as a constraint to be overcome, but can instead be more directly harnessed as a productive force in the quest for capital accumulation and corporate control (Goodman et al, 1987; Kloppenburg, 1988; Boyd et al, 2001). Just as the new biotechnologies have been used to harness the reproductive qualities of DNA, nanotechnologies are being used to harness the self-assembling properties and other novel features of materials at the nanoscale (Dupuy, 2007).

One of the primary aims of nanotechnological innovation is likely to be the fine-tuning of large-scale, standardized, mechanized and resource-intensive systems of production, with the aim of increasing productive output or achieving new efficiencies. Examples include: the potential for nano-chemical pesticides to be used more sparingly and precisely; the use of nanosensors to enable the more precise management of inputs within large-scale farming operations; and new food processing techniques and additives for reducing costs and wastage. At the same time, these large-scale standardized systems can also be rendered increasingly *flexible* by adapting agricultural systems to the ecological challenges of climate change and reduced water availability, or by enabling food manufacturers and retailers to more quickly adapt to changing consumer demands for convenience and nutritionally-enhanced foods.

Nanotechnology may facilitate a higher degree of *uniformity* across the agri-food system, while enabling a new level of product and system *differentiation*. Nature and materials are increasingly encountered as being constructed from a set of uniform, standardized and interchangeable nano-scale building blocks, as foods, seeds and

other inputs are able to be broken down into their constituent parts. Uniformity is in a sense being extended to the nano-atomic level. This nano-atomic uniformity would overlay and potentially extend the genetic, cellular, chemical and organic levels of uniformity that already characterize food production systems. At the same time, nanotechnology can also be used to re-differentiate these highly uniform and standardized inputs, products and systems, such as through the selective introduction of novel traits into crops or processed foods, or the micro-management of small areas within large-scale farms.

These technical capabilities enable both the inputs and outputs of agricultural and food manufacturing systems to be rendered increasingly interchangeable. For example, a range of crops could be used as biomass inputs to be transformed into a range of food or fuel products, and food ingredients can be reconstituted to mimic the properties of fats. This logic of interchangeability and ‘substitutionism’ further intensifies competition between the suppliers of these inputs and products (Goodman et al, 1987; Lawrence and Grice, 2008). But it also tends to increase competition between the purchasers of food products, as in the use of crops for food versus biofuel – a situation that may have contributed to recent global food price increases (Gordon, 2008; Piesse and Thirtle, 2009).

While new agri-food technologies have facilitated the production of highly standardised and processed food products, alternative agri-food trajectories based on principles of quality and diversity have also emerged, such as the rise and expansion of organic produce and the renewed demand for fresh and wholefood products. Many of these alternative trajectories have not involved technologies such as genetic engineering, and have in some cases been positioned in direct opposition to GM crops (Wilkinson, 2002). Due in part to their broader range of applications across the food system, nanotechnological innovations appear to have greater potential to support certain aspects of ‘quality’ food production and distribution, such as through the use of nano-packaging for transportation of high-value foods, reduced application of chemical inputs, the nutritional engineering and ‘enhancement’ of foods, the facilitation of more comprehensive supply chain monitoring, and so on. The organic industry has nonetheless resisted the introduction of nanotechnological inputs to date (Lyons, 2008).

In terms of environmental impacts nanotechnological innovations may, in specific circumstances, either ameliorate or intensify existing levels of resource use,

pollution emissions, soil and water degradation and loss of biodiversity in particular instances. For example, nanopesticides and precision farming may in some cases allow the more targeted and reduced use of chemical inputs on the farm. At the same time, nanotechnological innovations may facilitate the overall expansion of large-scale and resource-intensive systems of farming, food manufacturing and distribution, and the ecological problems associated with them.

Nano-scale technologies also introduce novel forms of ecological and health hazards, such as the potential toxicity of nanoparticles used on the farm or added to processed foods and food packaging. Despite the enhanced level of precision associated with the nanotechnological manipulation of nature at the atomic and molecular level, there is nevertheless still a considerable lack of precision in understanding and being able to control the consequences of these nano-atomic level manipulations (Dupuy and Grinbaum, 2006; RCEP, 2008).

Techno-corporate appropriation and integration

In *From Farming to Biotechnology*, Goodman and colleagues (1987) identified the appropriation by capitalist industries of traditional agricultural inputs, farming practices, as well as food processing and food preparation practices, as a central dynamic of the modern industrial food system. The concept of industrial appropriation conflates the two otherwise distinct processes of technological and economic appropriation. First, there is the initial technological appropriation of the discrete practices of food production and preparation via the development of technological instruments, inputs and food products, with the aim of extending control over nature and the technical process. Second, there is the subsequent economic appropriation of these discrete inputs and products through the processes of commodification, patenting, and corporate appropriation and control.

The nanotechnological platform provides new avenues for such technological and economic appropriation. New possibilities for the technological embodiment of farmers' pest management within controlled-release nano-pesticides, and for the appropriation of consumers' knowledge of health and safety through nutritionally engineered foods and 'smart' food packaging, illustrates this potential. The patenting of nano-scale materials, organisms and products itself entails an extension of techno-

commodification practices to the nano-atomic level, new possibilities for the control of products, markets and producers and, therefore, new avenues for capital accumulation. Nanotechnology extends and shifts the logic of technological and economic appropriation to the nano-atomic level of nature, in contrast to earlier forms of control and commodification which operate via the genetic and (micro) chemical levels.

A further distinction can be drawn between the initial appropriation of distinct practices, on the one hand, and the subsequent integration of these appropriated practices, on the other. The initially discrete technological and economic appropriations of food production and preparation practices have increasingly been integrated by means of further technological innovation in the form of technological packages – such as integrated seed-chemical packages – which have in turn facilitated the corporate integration and concentration of ownership and control of the food system. The integration and alignment of GM crops and particular herbicides in the form of herbicide-tolerant crops are a notable example.

Nano-scale technologies will facilitate the further re-integration and convergence of technologies, inputs and products across the food system, whether in the form of technology packages sold to farmers, or health-convenience packages sold to consumers (Dixon et al, 2006). The development of smart, interactive, environment-sensitive or cybernetic materials and products is important in this respect. For example, nano-sensors would form a part of the precision-farming packages aimed at integrating and coordinating various mechanical, chemical and irrigation technologies, while food processing techniques may combine and integrate the nutritional and convenience traits of food products. Some nanotechnological innovations may have cross-sector applications – such as the potential for using nanoencapsulation techniques to encapsulate both pesticides and nutrients. The development of food monitoring and surveillance applications also facilitates the vertical integration and coordination of agri-food supply chains, from farm inputs to supermarket checkouts and beyond.

To the extent that it is primarily the larger agri-food corporations that are able to develop, patent and market the new techniques and products of nanotechnology, these innovations will enable corporations to extend their market dominance within particular agri-food sectors, and will facilitate the corporate concentration of ownership and control across the food and non-food industries. The ETC Group

draws a direct connection between technological convergence and corporate convergence, arguing that technological convergence is ‘driving new and unprecedented corporate alliances across all industry sectors’, such as the convergence of the food and pharmaceutical industries facilitated by the new biotechnologies (ETC Group, 2008, p5).

Global agri-food corporations have extended and consolidated their ownership and control of the global food system enormously over the past few decades (Weis, 2007; Hendrickson et al, 2008). Philip McMichael (2005) and Harriet Friedmann (2005) have described this shift as one from the earlier ‘mercantile-industrial’ food regime to a ‘corporate’ or ‘corporate-environmental’ global food regime. At the same time, technologies of production, distribution and coordination have become increasingly central to the restructuring, integration and corporate concentration of food systems over this period. We therefore refer to the ‘techno-corporate’ character of the contemporary food regime – or the techno-corporate food paradigm – in order to highlight the dominance and centrality of both corporate and technological structures across the global food system, as well as the close interconnection between technological and corporate relations and forms of control (Scrinis, 2007; Scrinis and Lyons, 2007). Nanotechnology and other recent techno-scientific forms, such as genetic engineering, can to a significant extent be characterized as *corporate technologies*, in the sense that corporations not only predominantly own and control the technologies and their associated patents and products, but are also using these technologies as one of their primary strategies for integrating and extending their control over suppliers, for reducing or eliminating competitive markets, and for meeting shifting consumer demands (Heffernan, 1999; Boyd, 2003; Scrinis and Lyons, 2007; Otero, 2008).

Friedmann (2005) argues that the contemporary ‘corporate-environmental’ food regime is, in part, being maintained through the ability of corporations to selectively address a range of civil society consumer demands for higher standards in terms of quality, health and environmental standards, but that they do so by creating two distinct global markets targeted at wealthy and poor consumers:

The corporate-environmental food regime encapsulates two distinct corporate strategies for privileged and cash-poor customers across the globe... [T]he distinction between fresh, relatively unprocessed and low-

chemical input products on one side and highly engineered edible commodities composed of denatured and recombined ingredients on the other, describes two complementary systems within a single emerging food regime (Freidmann, 2005, p258).

Just as agri-food corporations are able to span the divergent trends and markets across the global food system, nano-scale technologies may also have the potential to span and lend a degree of technological unity to these distinct corporate strategies and trajectories – such as by augmenting the mass production of cheap standardized foods and by potentially enabling the production and distribution of more environmentally benign or quality-enhanced food products and production techniques. These technologies will also enable corporations to more rapidly and flexibly respond to – and adapt their large-scale production and distribution systems to – these changing market and ecological conditions.

This new round of technological innovations has the potential to reinforce and accelerate the corporate-based technological treadmill upon which primary producers, food manufacturers and consumers have been captured. This is because the ‘nanotechnological treadmill’ will be added to, and will overlay, the existing chemical and genetic treadmills, as well as the contemporary ‘nutrient treadmill’. Nanotechnological innovations also threaten to progress the types of agri-food system restructuring that have undermined and displaced small-scale producers, manual agricultural work and the demand for particular commodities. Agricultural applications such as nanopesticides and nanosensor-enabled precision farming systems, for example, may expand the use of mechanical and chemical technologies, or automate other skilled tasks or decision-making practices, and thereby threaten to further reduce and displace farm labouring work.

Conclusion: Regulation of, and resistance to, nano-food innovations

While these nano-food innovations are at a relatively early stage of research and commercialization, their development is being driven by corporate agri-food interests – largely in the absence of nano-specific regulations or public scrutiny. It remains to be seen whether the emerging regulatory regime, together with resistance from a range of possible sources – civil society organisations, consumers, particular agri-food

sectors such as organics, and competing corporate interests – might retard or re-direct the developmental trajectories of nano-food applications.

Until recently, there have been no national or international regulations to specifically target nano-food products, nor are there internationally agreed protocols for assessing the toxicity or environmental impacts of nanoparticles (Institute for Food and Agricultural Standards, 2006; Bowman, 2008). However, by early 2009, two significant moves along these lines had been made: the Canadian government introduced the world's first nano-specific regulations, calling for mandatory reporting on the use of nano-materials (Anonymous, 2009); and the European Parliament proposed that food produced via nanotechnology processes undergo risk assessment prior to approval, and called for the clear labelling of nano-foods. The outcome of this proposal may set a precedent for other countries and regions (European Parliament, 2009).

As has been the case with GM crops, the dominant discourse and the emerging regulatory regime for nano-foods is so far contained within a 'benefits versus risks' framework, whereby the claimed benefits of nanotechnological innovation promoted by industry and governments are taken as given, and with only a narrow range of (primarily toxicological) health and environmental 'risks' acknowledged as requiring regulation and management. Nevertheless, these early developments in nano-food regulation can be expected to have a number of flow-on effects. The introduction of risk assessment procedures may increase understanding of the risks associated with the production and consumption of nanotechnologies which might, in turn, improve the capacity to monitor and mitigate these risks. This would be a significant achievement given growing concerns over the products of nanotechnology: for example, the UK Royal Commission on Environmental Pollution (RCEP, 2008) has acknowledged that some manufactured nanomaterials may present hazards to human health and the environment, while the British Royal Society has urged caution in developing nanotechnologies, citing the very limited eco-toxicological research related to nanomaterials (RS/RAE, 2004).

It is possible that other countries and regions may follow the lead of Canada and the European Union in developing nano-specific regulations and labelling requirements, especially those seeking to comply with international standards to maintain international market access for agriculture and food exports. At the same time, it is also possible that corporate actors will take advantage of current regulatory

gaps, relocating nano-related testing and commercialization activities to those unregulated countries and regions. In these circumstances, nano-foods could end up being sold in those countries unable or unwilling to regulate health, safety and other issues. This may result in a similar situation as has occurred with GM crops over the last decade where, in response to the introduction of tighter regulations and consumer resistance in the north, production and consumption of GM crops and foods shifted from Northern to Southern countries (McMichael, 2001). If the same trend occurs with nanotechnology, this may leave countries in the South as the testing ground for the new nano-foods.

In recent years, civil society groups have become increasingly active in their opposition to agri-food nanotechnologies. Friends of the Earth and the ETC Group have led international calls for moratoria on the release of any products of nanotechnology until adequate assessment, regulation, labeling requirements and public involvement in decision making related to nanotechnologies are established (ETC Group, 2004; FoE, 2008; Lyons and Scrinis, forthcoming). These and other civil society groups have also highlighted the role of nanotechnology in the ongoing commodification and corporatization of agriculture and food systems.

Nano-food applications also raise many issues of concern to consumers, evoking responses reminiscent to those associated with GM foods (Kearnes et al, 2006). In one Swiss survey, a majority of consumers did not want to eat nanofoods, or foods wrapped in nanopackaging (Siegrist et al, 2007). Similarly, a US survey reported that only 7 per cent of survey respondents were prepared to purchase foods produced using nanotechnology, while 62 per cent wanted more information about the health risks and benefits prior to considering buying nano foods (Peter D. Hart Research Associates, 2007).

Many questions remain regarding the extent to which the concerns raised by civil society groups and the public will shape future trajectories of the nano agri-food industries. In recent years a number of models for public engagement have been proposed in an attempt to give voice to the broad range of concerns associated with the development of nanotechnologies. Many of these models, however, have been criticized both for the limited extent to which diverse interest groups have been included in deliberative dialogue, and for the gaps between processes of deliberation and the actual formation of policy and regulations related to nanotechnologies (Lyons and Whelan, forthcoming). These limits to public participation may exacerbate

mistrust in regulators, thereby fuelling opposition to nano foods. This was certainly the outcome of deliberative governance approaches related to GM foods, whereby consumers' lack of trust in regulatory structures heightened their perceptions of the risks of eating GM foods – circumstances that have, in part, resulted in global opposition to GM crops and consumer boycotts of GM foods (Cocklin et al, 2008).

Acknowledging the growing uncertainty associated with future nano-food applications, the organic agri-food sector has taken steps to exclude nanotechnologies. In 2008 the UK Soil Association – the world's oldest organic certifier – prohibited the listing of products and processes derived from nanotechnology from their organic standard due to the unknown ecological and health risks associated with exposure to nano-particles. Organic certifiers around the world – including the Biological Farmers of Australia – are beginning to follow this lead, and it is likely other more general food standards may move to exclude nano products and processes (Lyons, 2008).

It is not yet clear how supermarkets and the retail sector will respond to nano-food applications. On the one hand, we might expect their support for nano applications, such as remote sensing and tracking devices that offer improvements in the efficiency of tracking and sales information, or nano-packaging materials that offer marketable characteristics – such as longer shelf life – to consumers. On the other hand, due to their sensitivity to consumer opposition and the potential loss of market share, supermarkets might also exclude nano foods and other nano-based products, as they did in the controversy over GM foods, when many retailers in the UK went GM-free in response to consumer backlash. German supermarket chain Metro has already responded to consumer opposition by recalling consumer loyalty cards that utilized nano-based identification tags (Busch, 2008).

While the corporate science sector continues to invest heavily in nano agri-food research and development, the commercial success and developmental trajectory of nano-food applications are yet to be determined. Many scientists and government agencies are joining civil society groups to call for effective risk assessment procedures related to nano-food products and processes. At the same time, on-going opposition from the organic sector, retailers and other players in the agri-food sector, as well as community acceptance or rejection of public participation processes, will play a vital role in shaping the trajectory of this agri-food technology.

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