Emerging Technologies

Edited by Edna F. Einsiedel

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From Hindsight to Foresight

UBCPress · Vancouver · Toronto

17 16 15 14 13 12 11 10 09   5 4 3 2 1

Printed in Canada with vegetable-based inks on ancient-forest-free paper (100% post-consumer recycled) that is processed chlorine- and acid-free.

Library and Archives Canada Cataloguing in Publication

Emerging technologies : from hindsight to foresight / edited by Edna F. Einsiedel.

Includes bibliographical references and index.
ISBN 978-0-7748-1548-2

1. Biotechnology. 2. Genomics. 3. Nanotechnology. 4. Technological innovations—Social aspects. 5. Technology—Social aspects. I. Einsiedel, Edna F.

T14.5.E445 2009   303.48'3   C2008-904298-0

Canada

UBC Press gratefully acknowledges the financial support for our publishing program of the Government of Canada through the Book Publishing Industry Development Program (BPIDP), and of the Canada Council for the Arts, and the British Columbia Arts Council.

This book has been published with the help of a grant from the Canadian Federation for the Humanities and Social Sciences, through the Aid to Scholarly Publications Programme, using funds provided by the Social Sciences and Humanities Research Council of Canada.

This project was made possible with assistance from the Canadian Biotechnology Secretariat Office and the GE3LS Project (Genomics, Ethics, Environmental, Economic, Legal, and Social Studies) funded by Genome Canada. Support from these organizations is gratefully acknowledged.

UBC Press
The University of British Columbia
2029 West Mall
Vancouver, BC V6T 1Z2
604-822-5959 / Fax: 604-822-6083
www.ubcpress.ca

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Acknowledgments

We thank Genome Canada for its support of this book project. A few of the chapters in this book were developed from papers commissioned by the Canadian federal government's Canadian Biotechnology Secretariat and presented at a 2005 symposium in Ottawa sponsored by the GE3LS Alberta project (Genomics, ethics, economic, environmental, legal and social studies), funded by Genome Canada and the Biotechnology Secretariat.

Abbreviations

BRS	Biotechnology Regulatory Services
CBD	Convention on Biological Diversity
CFIA	Canadian Food Inspection Agency
CIHR	Canadian Institutes of Health Research
CSGA	Canadian Seed Growers' Association
EPA	Environmental Protection Agency
EPC	European Patent Convention
EU	European Union
FDA (US)	Food and Drug Administration
GM	genetically modified
GMO	genetically modified organism
hESC	human embryonic stem cell
IP	intellectual property
IPRs	Intellectual property rights
NGO	nongovernmental organization
OECD	Organisation for Economic Co-operation and Development
PGR	plant genetic resource
PMF	plant molecular farming
PMIP	plant-made industrial product
PMP	plant-made pharmaceutical
PNTs	plants with novel traits
PRBs	plant breeders' rights
REBs	research ethics boards
SCNT	somatic cell nuclear transfer
TCPS	*Tri-council policy statement*
TK	traditional knowledge
TRIPS Agreement	Agreement on Trade-Related Aspects of Intellectual Property Rights
USDA	United States Department of Agriculture
WHO	World Health Organization
WTO	World Trade Organization

Emerging Technologies

Introduction: Making Sense of Emerging Technologies

Edna F. Einsiedel

This book is about emerging transformative technologies. Emerging technologies can be described in several ways. These are technologies in the developmental stage of production, perhaps not yet fully exploited by firms, or in the early stages of commercialization. For a number of these, basic research may still be taking place, and the projections of potential applications remain just that–projected aspirations and hopes. The term *emerging technologies* has been used to describe information and communication technologies (perhaps three decades ago), and more recently, biotechnology, genomics, and nanotechnology.

These emerging technologies are also called "strategic" technologies–so labelled because national investments and aspirations ride on them. They are also strategic in the sense that they involve forward thinking and planning. Numerous countries identify technologies they consider strategic to their national interests and global competitiveness, build national systems of innovation and develop strategic plans around them, develop policy approaches, and finance a variety of activities, from research and development initiatives to human resource activities.

Finally, they are revolutionary or transformative. We do not use this word lightly. A technology is "revolutionary" when it has the capacity to change a wide range of sectors. These transformative technologies involve shifts in traditional relationships, can be socially disruptive as much as they can bring about greater cohesiveness, and can bring about new institutional rules and arrangements. Think about the taken-for-granted things the automobile has spawned, for example, as described in a journalist's feature on automobiles:

> drive-through restaurants, drive-by shootings, drive-up banks, gas stations, suburbs, motels, back-seat boogies, body shops, paved roads, parking lots, traffic cops, truck stops, decent factory wages, smooth-talking car dealers, highway deaths, gridlock, pollution, "are-we-there-yet?" family vacations. (*USA Today* 1996)

Emerging technologies are projected to have broad-ranging impacts on many areas of life. Biotechnology, for instance, has had, and continues to have, impacts on what we eat and how our food is produced, how we view and how we treat disease, how we clean up the environment, even how we carry out justice in our judicial systems with DNA evidence. This wide-ranging set of implications and the nature of impacts contribute to making a technology revolutionary.

When we look back to the histories of various technologies now embedded in society–from vaccines to computers, from electricity to enhanced foods–we see historical trajectories that have led to life and societal changes, from reduced mortality to revolutionized working conditions. These histories also remind us that, once upon a time, these technologies may not always have been greeted with excitement and anticipation.

What is interesting about the introduction of new–and particularly revolutionary–technologies today is the extent of societal attention accorded to them. This is because of the ubiquity of information sources; the desire of governments to make a given technology "happen" (thus creating the conditions for such a happening to occur); the savvy of social groups in society as they try to raise the alarm bells about the potential negative impacts or, alternatively, to push through the development trajectory at a more rapid pace; or the greater attentiveness of the average citizen.

Such attentiveness may develop from experiences with older technologies, when controversies surrounded their introduction, led to their demise, or brought about a redesign more in keeping with public and stakeholder demands or interests. This attention can also be aroused by the media, whose attention span is only as short as the next big controversy but whose multichannel ubiquity can continue to pique public interest.

In this book, we have chosen to investigate technologies that are in precommercialization or early commercialization stages. These include nanotechnologies, pharmacogenomics, molecular farming, stem cell research, and newer biotechnology applications–technologies or their applications that all have connections to the life sciences. Nanotechnology, of course, embraces a range of applications that connect with the life sciences but also goes beyond. We include it here as another example of "the next big thing." In this respect, the choices for our focus are somewhat arbitrary. On the other hand, as I pointed out earlier, these are "revolutionary" and strategic technologies. Nanotechnology, still in its technological infancy, is similarly expected to have impacts on the types of materials we use and how they are applied, how we diagnose and treat disease, how we produce energy, or how we communicate. It is already identified as key to national innovation interests for many industrialized countries.

Perhaps because of the potential impacts of these technologies, they have been taken notice of much earlier in the innovation process. In addition to the scientific community, publics and policy makers are in on the conversations and debates early in their developmental trajectories. "Everyone" includes the scientists working away on various aspects of the technology, the institutions these scientists belong to, the potential and actual venture capitalists ready to jump on the next big (or small) thing, the media who are alerted by early exciting prognostications, other stakeholders who see the potential benefits and the potential risks, and the publics who have become earlier voyeurs, watching the various aspects of the technology as these are being rolled out in fits and starts, or as claims and counterclaims are being made about them in public arenas.

In this book, we focus on a number of actors in the landscape of emerging technologies. The first group includes the various publics who are going to be eventual users, who currently bankroll some of the research through their tax dollars, who sometimes make decisions in the political sphere through the ballot box or through their choice of political decision makers, or who may bear a greater burden of risks or may have a larger stake in the promised benefits than others.

The way publics have been viewed has changed over time. Perhaps the earliest way of envisioning "the public" involved a unidimensional view of a monolithic public, subject to the vagaries of information disseminated from the so-called experts. This simplistic view has changed significantly, with publics (plural emphasis) engaged or inattentive at various times, occupying different roles at different times–citizen, consumer, patient, environmentalist–being naive or displaying expertise, becoming active or noncommittal depending on context and circumstance. One important contextual difference has been identified in terms of the confluence of geography and culture, evident in transnational differences on the reception of biotechnology applications (Gaskell et al. 2001; Hallman et al. 2004).

What we have also learned is that other actors' views of publics are also changing. While others have talked about publics as "a second hurdle" (Von Wartburg and Liew 1999, 34) after regulatory development, the increasing prominence given to publics today, if one is to go by public policy pronouncements, is less in terms of hurdle and more in terms of "participant" in the technology development process.

Policy makers constitute another set of important actors in the public arena. These decision makers do not make decisions in a vacuum; rather, they engage with other stakeholder groups, interact with their counterparts in the global arena, and attend to or play active roles in international policy initiatives.

We also focus on processes. Some of these are common across technologies. How do regulations and policies come about? Who gets consulted? What factors were considered for particular policy stances and why? What challenges have been faced and are ongoing in regulatory development?

In examining each group of technologies, we suggest that a technology becomes emergent when it assumes its form in the public sphere–when others not necessarily involved in the technology's direct development are able to examine its gestation, often through the media or through the activities of various actors. What used to be an inside look that few were privy to is now occurring on an open stage. This happens partly because scientific institutions (such as the leading journals or academic institutions) are linked even more directly to popular channels, because scientists have become more strategic in their use of these popular channels, because the media are constantly on the lookout for stories that whet the public imagination, because "life-enhancing" stories are continuing fodder for the public imaginations, and because values of particular groups stoke an oppositional interest.

Given this context, the appearance of new technologies in the public arena is occurring much earlier in the innovation trajectory, many becoming a fixture in the public landscape even as early as the stage of technology design. In some ways, this may be occurring from the benefit of hindsight. That is, when we look back to the experience of older technologies–nuclear power and GM food are particular examples–we see that discussions of these technologies occurred at the commercialization stage when it was "too late." Those engaged in nanotechnology design see this as a key lesson to be learned (see, e.g., Royal Society and Royal Academy of Engineering 2004).

The currency of these public conversations is hope–but hope is meaningful only in the context of fears; risks are meaningful only in the face of uncertainties. And so, the studies and commentaries presented in this book are early explorations of what these emerging technologies look like from the vantage point of representations among publics and stakeholders, discursive activities in legislative rooms, informal and formal deliberations among citizens or policy makers. These are early impressions in some instances, longer term and more developed views in others. We expect these pictures–snapshots at this point in time–to similarly evolve with the technologies' evolution. How these different interactions develop over time remains to be seen.

We use the themes of hindsight and foresight for examining these emerging technologies. There are lessons to be learned from the experience of earlier biotechnologies and, indeed, the experience with GM foods has become the seminal case for emergent technologies.

We also put forward our base assumption–that technology is *both* social and technical–and this assumption is embedded in how we look at the innovation processes behind these emergent technologies. This approach argues that an understanding of innovation and particularly the question of how a technology is accepted or rejected is a social–as well as a technical–one. If a technology flounders, fails, or succeeds, what criteria or factors help to explain this and why, who defines these criteria, who are excluded?

Part 1 provides hindsight perspectives, looking at what we know about publics and agricultural biotechnology and issues around ownership of knowledge. Who owns what under what conditions remains a highly contentious issue. This is particularly so since the US Supreme Court ruled in 1970 that living organisms were patentable. Ever since this ruling, the trajectory of intellectual property processes has followed a contentious path: What weight should be given to social-ethical concerns in relation to determining patentability, and how should these concerns be accommodated, if they should be at all? What limits should be placed on patent holders' rights? For example, should farmers who use patented seeds be allowed to save and reuse those seeds? How should issues around traditional knowledge–which is shared–be addressed, particularly in the context of companies utilizing elements of such knowledge?

By using intellectual property questions and specifically those about patents as a lens, we examine how publics assess one aspect of technology innovation. Chapter 3 summarizes what we have learned from various studies on publics and patents, the metrics used, and the trade-offs made.

From agricultural biotechnology we move in Part 2 to the hybrid biotechnologies–the transgenics that bridge the worlds of agriculture and medicine. These include transgenic plants modified to produce drugs and vaccines, and transgenic animals that are modified for a similar variety of purposes, such as food and pharmaceutical production.

The questions raised about these technologies are a similar mix of public reaction and concern and debates about economic risks and benefits, environmental challenges, and safety issues, not to mention the inchoate concerns raised by some stakeholder groups that may range from revulsion to fear to anxiety. Questions about regulatory efficacy and trust in those at the technology's helm are often bound up with public views. At the same time, the challenges of appropriate and effective policy and regulation have remained with us.

Moving to the world of medicine and health, issues around cells, tissues, and organs are blended in with questions that resonate with those raised around knowledge: whose cells and tissues, derived from what source, for what purpose, and with what impacts? In the case of stem cells, the issue of origin has never been more contentious and has had important impacts on policy positions. By what values are these decisions made? Human dignity has been a frequent watchword in debates involving the body but, in Chapter 9, on stem cells, this taken-for-granted concept is interrogated and challenged.

Pharmacogenomics–the study of the genetic basis of differential drug reactions–offers a window into a world opened up by the mapping of the human genome. The lens gets focused even more tightly on groups and subgroups bound by similarities of "race" or ethnicity. Here, questions are raised about basic biological dogma of genes as major determinants of health. This basic dogma gets murky in the arena of risks as defined by individual and group responses to drugs. The double-edged sword of differential drug responses is nowhere better illustrated than the first pharmacogenomic drug on the market, BiDil, a heart drug said to be more efficacious for African Americans. How are expectations framed around this drug during its early discussions in the regulatory arena? A further procedural and substantive question can be raised around informed consent, with much pharmacogenomic research resting on tissue banks. What challenges are confronted with consent processes based on individual autonomy when genetic information implicates other members of the family?

Finally, in Chapters 13 and 14 we look further into the future with nanotechnology, with its forerunner applications already making their appearance in the market (wrinkle-free pants, anyone? Or deep-cleansing nanomolecules in your face cream?). Like biotechnology, nanotechnology is a bridging technology, an enabler for a variety of older approaches. It offers a bridge between the life and material sciences. The publics of nanotechnology are as much a product of our researcher imaginations as they are products of identifiable individuals or organized groups whose activities are highlighted in the media; the stakeholders for this technological realm are actors that have appeared in plays from other technological pasts (ETC 2004; Einsiedel and McMullen 2004).

Ultimately, the questions we ask are, what kind of world do we prefer to have, and how do we get to this point? Who decides, and how? This is the governance question. In Part 3, we reflect on the complexities of policy development and ownership of knowledge and the question of processes of decision making. Again, these are hindsight and foresight questions.

Many lessons have been learned, quite often by muddling through rather than by systematic and planful approaches. For some in the policy community, the admonition of being safe rather than sorry–by looking before making a leap–(formally known in terms of the precautionary principle) has become increasingly accommodating of risk-analysis metrics. On the other side of the fence, those who have lived by the rule of "sound science" and science-based risk assessment have had telling experiences of bumping up against the realities of economics and social values. They similarly have had to modulate and accommodate.

At the same time, questions about knowledge ownership and control have not been as clear-cut and straightforward as patents systems would have us believe. If the innovator enjoys the protection of and benefits from intellectual property regimes, what responsibilities does he or she carry when technology use goes awry? The controversies over StarLink corn–approved for animal feed but not for human consumption–found in taco shells in the United States, and the ProdiGene case of transgenic corn modified for pharmaceutical production and inadvertently found in the next round of field crops are important reminders of lingering questions on liability and responsibility.

The book concludes by bringing together the key themes of hindsight and foresight from recent and emerging technologies, examining lessons across a variety of technologies. These lessons are as much about the processes of societal and organizational learning as they are about the lessons actually learned.

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Part 1
Hindsight Learnings

1
GM Foods in Hindsight
William K. Hallman

Worldwide, billions of dollars have been spent on research and development of genetically modified (GM) crops to create new and improved sources of food, feed, fibres, fuels, and pharmaceuticals. Widely touted as a transforming technology, agricultural biotechnology was expected to change agriculture in ways that would rival the gains made during the green revolution. As Shoemaker, Johnson, and Golan (2003, 32) write, "Biotechnology is often associated with promise . . . promise to feed the world, promise to reduce environmental harm, promise to expand agricultural markets and production possibilities, promise to create products that consumers want. Farmers in the United States seem to be sold on these promises."

Indeed, GM crops have been adopted by farmers at an extraordinary rate over the past decade. Since they were introduced in 1996, farmers have consistently increased the acreage planted with biotech crops by double-digit growth rates every year. As a result, the amount of acreage devoted to GM crops has increased more than fifty-fold worldwide in ten years (James 2005).

Significantly, consumers in the countries that produce the majority of GM crops, including the United States, Argentina, Canada, Brazil, and China, seem to have paid little attention to the technology (Gaskell et al. 1999; Hebden and Hallman 2005). At the same time, GM food continues to provoke anxiety among many consumers in other parts of the world. Reflecting perceived consumer sentiment, governments in Europe, Japan, South Korea, and parts of Africa have instituted public policies that effectively restrict the planting or sale of GM food products. The resulting international trade disputes over GM agricultural commodities have highlighted complex issues involving the role of science and consumer sentiment in establishing policies intended to regulate the creation and adoption of new technologies and their products.

Thus, while GM crops have been widely adopted in some parts of the world, they are deeply held in suspicion in others, belying the initial promise of GM foods. As such, reactions to the emergence of GM foods may offer important lessons applicable to the introduction of other new and potentially controversial technologies. Here then, are some of those lessons.

Awareness of and Familiarity with New Technologies Are Often Surprisingly Low

That a new technology becomes controversial does not necessarily mean that it has captured the full attention of most people in society. Stories about biotechnology and GM foods and the controversies they have engendered have been widely reported in the media for more than two decades. So, it is difficult to believe that most people know little about the technology or the issues surrounding it. Yet, a 2005 survey of Canadians and Americans conducted by the Canadian Biotechnology Secretariat confirms that most people in North America don't have a great deal of familiarity with biotechnology as a whole. While the majority now say they have *heard* of biotechnology, fewer than 10 percent of Canadians or Americans say they are "very familiar" with it. In fact, about as many Canadians (13 percent) and Americans (9 percent) say they are "not at all familiar" with biotechnology as say they are very familiar with it (Walker 2005).

Studies conducted in China (Huang et al. 2004) and in South Korea (Hallman et al. 2005) show similar results. Few Chinese (10 percent) say that they know "a great deal" about biotechnology, while most say that they have heard or read "some" (34 percent), "not much" (23 percent), or "nothing at all" (33 percent). In South Korea, where the government has placed emphasis on becoming a leading developer of biotechnology products and where there has been a great deal of media coverage, more people indicate that they are familiar with biotechnology. Still, nearly two-thirds (63 percent) of South Koreans say that they only heard "some" about biotechnology, while 18 percent say that they had heard or read "a great deal." Thirteen percent say that they have heard "not much," and 6 percent say that they had heard nothing at all.

Even in Europe, where the controversy over biotechnology has perhaps been most heated, research suggests that most Europeans are not very familiar with biotechnology either. When asked whether they had heard of each of three applications of biotechnology, on average, the respondents reported having heard of only about half (1.79) of them (Gaskell, Allum, and Stares 2003).

Given that most people say that they have not heard or read very much about GM foods and that they are not very familiar with them, it is not surprising that most Americans and Canadians also say that they have not talked very much about them. More than half (53 percent) of Americans and 41 percent of Canadians say that they have never had a conversation about

GM foods (CBS 2005; Hallman 2005). Similar results have been found in the United Kingdom, Greece, Portugal, Spain, and Belgium, though people in the United States and Canada are considerably less likely to have talked about GM foods than their counterparts in Europe as a whole and substantially less likely than those in Germany and Denmark, where reported discussion is at its highest (Gaskell, Allum, and Stares 2003).

The fact that most people in North America do not seem to be actively discussing GM food suggests that one should not assume that controversy over a technology will necessarily create a place for it on the national agenda, nor will it lead to consumer knowledge, understanding, or attentiveness. As Hallman and Metcalfe concluded in 1994, "While the battle over biotechnology has raged between experts, most of the shots have passed over the heads of the non-combatants" (36).

News Coverage about a Technology Does Not Necessarily Make a Lasting Impression on People

Many of the controversies about biotechnology have been particularly centred on genetically modified food. As a result, hundreds of news stories have appeared in newspapers, on television, and on the internet about agricultural biotechnology since the early 1990s (Nisbet and Lewenstein 2002; Ten Eyck and Williment 2003; Thompson and Dininni 2005). Yet, when asked how familiar they are with GM food, less than a sixth of Canadians and Americans say they are "very familiar." More than half of Americans (54 percent) and Canadians (56 percent) report that they are only "somewhat familiar," and a third of both Canadians and Americans say that they are either "not very familiar" or "not at all familiar" with GM foods (Walker 2005).

In the Canadian Biotechnology Secretariat's study, Canadians and Americans were asked if they had read, seen, or heard "a lot," "a little," or "nothing" about issues surrounding GM foods within the three months prior to being interviewed, in January 2005. Consistent with their answers concerning their familiarity with GM foods, more than half of the Canadians (56 percent) and Americans (52 percent) reported that they had heard only "a little" about GM food issues. Moreover, more than one-third of the Americans (39 percent) and 29 percent of the Canadians responded that they had heard "nothing" about GM food issues (CBS 2005). In fact, when Americans were asked if they could remember events or news stories related to GM foods, fewer than one in five could recall any (Hallman et al. 2004).

Many New Technologies Are Invisible

Many important emerging technologies, especially those targeted at the genetic, cellular, or nano scale, are literally invisible to people. They work at a level that cannot be seen and, because of this, their mechanisms are often misunderstood.

These technologies are often figuratively invisible as well. Unless it offers a specific consumer benefit or some other advantage that can be advertised, it is unlikely that a particular technology will be purposely promoted as part of a product. Thus, consumers may often purchase products brought about through scientific breakthroughs about which they have heard or read little and which they do not fundamentally understand. For example, one of the fundamental problems with public understanding of GM technology is that although the morphological and functional consequences of genetic modification are sometimes apparent, current GM crops are largely indistinguishable from their conventionally bred counterparts. They look, smell, and taste the same as non-GM foods. As such, without special labels, it is generally not possible for people to readily identify even whole grains, fruits, or vegetables that have been genetically modified and virtually impossible for people to recognize processed foods that contain GM ingredients. This helps to explain why, despite the ubiquity of GM ingredients in the food system, national surveys show that most Americans are generally unaware of the presence of GM foods on their own plates (Hallman et al. 2002; Hallman et al. 2003; Hallman et al. 2004). Fewer than half of Americans realize that foods containing GM ingredients are available in supermarkets (Hallman et al. 2004) and fewer than one in four believes they have consumed GM foods (Pew Initiative on Food and Biotechnology 2005). Moreover, many of those who do believe that GM foods are sold in supermarkets are confused about which GM products are actually for sale. While three-quarters of those who believe that GM foods are available in supermarkets say that products containing GM corn are for sale, and 65 percent correctly believe that products containing GM soybeans can be purchased, many more apparently are convinced that they are eating GM tomatoes, GM chicken, and GM rice, none of which is available for purchase in the United States (Hallman et al. 2004). For other "invisible" emerging technologies, this suggests that it is not possible to rely on the ubiquity of the technology or its applications to drive consumer awareness.

Invisible Technologies May Be Perceived as Having Invisible Consequences

That the products of agricultural biotechnology are not implicitly visible means that people are often unaware of their exposure to them, and therefore unable to assess their potential effects. This can have both positive and negative consequences.

Upon learning that they have been eating GM foods for more than a decade, some consumers in North America may decide that because they have been doing so without any apparent adverse consequences, these foods are fundamentally safe and so they will continue to eat them. But it is also possible that some people will feel that they have been tricked into eating GM products without their consent; this may potentially lead to a backlash among angry consumers. Moreover, many consumers understand that scientists cannot categorically assure that there will be no long-term health consequences of consuming GM ingredients. As such, it is possible that some consumers will attribute otherwise medically unexplainable symptoms, illnesses, or other health problems to their unknowing consumption of GM foods. For example, in September 2000, after the discovery of the accidental contamination of taco shells and other corn products by a variety of GM corn not approved for human consumption, at least twenty-eight people reported allergic reactions to the US Centers for Disease Control. However, after testing, none of those reporting unexplained symptoms was found to have demonstrable allergic reactions to the corn (CDC, National Center for Environmental Health 2001).

Because many emerging technologies are both literally and figuratively invisible to consumers, and most visits to physicians involve symptoms without medical explanations (Kroenke and Mangelsdorff 1989), the potential to blame unexplained illnesses or symptom syndromes on the effects of invisible technologies seems particularly great. Without credible alternative explanations, it may be difficult to convince people that these technologies may not be ultimately responsible for their problems.

Making Invisible Technologies Visible May Have Unintended Consequences

In part, the lack of public awareness of GM foods in the United States is likely because they are not required to bear labels that would make their GM content apparent. According to a 1992 US Food and Drug Administration (FDA) policy, special labels for foods derived from new GM plant varieties are required only under several particular circumstances. Specifically, labels are necessary to notify consumers if the food derived from GM plants is no longer generally considered to be equivalent to its non-GM counterpart, in which case the food product also needs to have a new name. A GM food product also must be labelled if it has a new use, if a new nutritional characteristic not customary to the product is introduced, or if a known allergen is introduced that is not inherent to the product (FDA 1992). Significantly, however, although these regulations require that labels be used to alert consumers when the characteristics of a familiar food product have been substantially altered through the use of GM ingredients, the labels do not need to say that the change was produced through the process of genetic modification. As a result, there are no current regulations requiring GM foods be identified as such in the United States. However, voluntary guidelines drafted by the FDA in 2001 permit food manufacturers to voluntarily label their products as containing GM ingredients (FDA 2001). Similarly, food manufacturers can label their products as containing no GM ingredients if they choose to, as long as the label does not state or imply that the product is superior because it does not contain such ingredients.

Canada has adopted a similar voluntary labelling standard, with regulatory oversight focusing on a scientific assessment of the characteristics and associated risks of a GM food product before approval for sale. Like the US policy, it is mandatory in Canada for manufacturers to label *any* novel food product where there is a health or safety concern, such as the introduction of a known allergen, or if the composition or nutritional value of the food has been substantially changed. Moreover, in Canada, as in the United States, it is not mandatory to label any food (including GM food) for the process by which it has been developed. As such, under current regulations, in Canada a producer is not required to label a product produced through a process of biotechnology (CBS 2005; Canadian General Standards Board 2004).

This voluntary labelling approach assumes that the technology is generally safe and that market forces should ultimately determine the fate of GM foods. In doing so, the Canadian and US policies attempt to support consumer sovereignty, allowing people to make choices about the foods they buy (Thompson 1997), without imposing unnecessary regulatory costs. These voluntary labelling policies theoretically give consumers who want to avoid GM foods the ability to do so without forcing additional costs on the majority who are assumed not to have such a preference, and, based solely on scientific assessments of the risks of GM foods, *should not* have such a preference (Hallman and Aquino 2005; Moon and Balasubramanian 2004).

In contrast, the European Union (EU) has taken a different approach, promulgating a law that requires any food product that contains more than 0.9 percent genetically modified material to be specially labelled as such (Alvarez 2003). Moon and Balasubramanian (2004) argue that this EU mandatory labelling policy reflects two regulatory principles. The first permits the separation of scientific assessment of risk from the management of those risks. This allows EU regulatory agencies to consider important economic, political, and societal concerns apart from whether the technology presents particular health or environmental risks. The second is the application of the precautionary principle, which requires ongoing scientific assessments of the technology to resolve any questions about its possible adverse effects on human health or the environment.

Like the US and Canadian policies, the EU labelling policy is based on the idea that the cumulative decisions of individual informed consumers should ultimately determine whether GM foods survive in the marketplace. However, unlike the US and Canadian approaches, the EU policy presumes that although no problems have yet been linked with GM food products, there are uncertainties that need to be recognized. By requiring labels, the EU policy theoretically gives the majority who presumably would prefer to avoid GM foods the ability to do so, while passing the additional costs created by the mandatory labelling system onto those who want to produce or consume GM products.

The two labelling approaches are based on the idea that they will allow informed consumers the ability to make choices in the marketplace that will determine the future of the technology. Indeed, the implementation of the EU labelling policy theoretically ends a de facto regulatory ban on GM food products (Alvarez 2003). Ironically, however, neither policy effectively gives consumers the choices they are intended to provide. Food processors are reluctant to put GM labelled products in the marketplace because they fear that consumers will interpret these labels as warnings that the products are of inferior quality or are unsafe. As a result, manufacturers are concerned that GM food labels will cause consumers to reject any products bearing them (GMA News 2001; Food Safety and Inspection Service 2002). Therefore, while most processed foods in the United States and Canada are likely to contain at least traces of GM ingredients, major North American food manufacturers have decided not to label their products as containing GM ingredients (Hallman and Aquino 2005). In the European Union, most supermarkets have chosen not to stock products containing GM ingredients on the grounds that many clients would decide to shop somewhere else (BBC News 2006).

So, policy makers face a dilemma. Consumer opinion surveys show that, when asked directly, consumers around the world show very high levels of support for the labelling of GM food products (Einsiedel 2002). For example, when Americans are asked if they want GM food labels, more than 90 percent say they do, including 95 percent of those who say that they never pay attention to food labels (Hallman et al. 2003). These results are consistent with the position of advocates of mandatory labelling, who argue that people want to retain the ability to choose between GM and conventional food products.

However, some research also suggests that a declaration of the presence of GM ingredients on a food label is likely to cause the product to be rejected by consumers (Hallman et al. 2003). In a national survey of attitudes toward GM foods, more than half (52 percent) of Americans said that a GM food label would make them less willing to purchase the product. In addition, focus group results reported by Hallman and Aquino (2005) suggest that the consumers most familiar with GM food would use the labels to avoid products bearing them and those least familiar would very likely see GM food labels as warnings that they should be concerned about the contents of the products. These results are consistent with the position of those opposing mandatory labelling, who argue that the likely effect of GM labels would be to lead consumers to reject foods made with GM ingredients, although there is no scientific evidence that GM products are inferior or unsafe. Widespread rejection of GM products would likely cause them to disappear from supermarket shelves, thereby reducing real consumer choice.

The paradox, of course, is that without products on the shelves bearing GM labels, it is unlikely that consumers will become much more aware of the presence of GM foods than they already are. Yet, until consumers become more familiar with the technology, they are likely to reject products associated with it.

People Often Lack the Scientific Background to Understand New Technologies

Given that most people say they are not very familiar with GM foods and have not heard a great deal about them, it is not surprising that most also say they do not know very much about them. When asked how much they know about GM foods, most Americans say they know "very little" (48 percent) or "nothing at all" (16 percent). Far fewer say that they know "some" (30 percent) or "a great deal" (5 percent) (Hallman et al. 2005).

That most Americans know little about biotechnology and GM foods is also borne out by studies of factual knowledge about genetics and biotechnology (Hallman et al. 2003; Cuite, Aquino, and Hallman 2005). To assess respondents' actual knowledge of science and genetic modification, they were quizzed using a set of eleven true-or-false questions based on those originally developed for use in the Eurobarometer surveys of European attitudes toward GM foods (Gaskell, Allum, and Stares 2003). More than half of the respondents (52 percent) received a failing grade of less than 70 percent correct and only 4 percent of the sample answered all the quiz questions correctly. There was only a moderate relationship between what Americans think they know about science and objective measures of their actual knowledge. The correlation between self-assessed knowledge of science and technology and quiz scores was 0.38. The correlation between self-assessed knowledge of genetic modification and the quiz scores was 0.35.

This lack of correlation between what people think they know about the science of genetics and biotechnology and what they actually know is important in understanding how people may approach learning about emerging technologies. Those who overestimate what they know about science and technology are unlikely to recognize the gaps they have in their knowledge about biotechnology and so are unlikely to seek information to fill in those gaps. In contrast, those who underestimate their knowledge are unlikely to recognize that the basics of biotechnology are not as difficult to understand as they may assume. In both cases, because of a lack of understanding of what they already know or do not know about a technology, people may not be particularly motivated to try to learn more about it.

Knowing More about a Technology Is Not Necessarily Related to Public Acceptance

The idea that knowing more about the science behind a specific technology will lead to greater approval of that technology is relatively common throughout the scientific literature. Indeed, some studies have found a positive relationship between increased knowledge and approval of the application of science (Evans and Durant 1995; Hayes and Tariq 2000; Gaskell et al. 2002; Allum, Boy, and Bauer 2003; Sturgis and Allum 2004). However, the findings are not entirely consistent, with other studies finding no relationships between knowledge and acceptance (Pfister, Bohm, and Jungermann 2000) or curvilinear relationships between the two (Jallinoja and Aro 2000; Peters 2000).

Some studies have also shown both positive and negative relationships between knowledge and approval, and that some types of knowledge may be more influential than others. Gaskell et al. (1999) compared American and European data to examine the relationship between knowledge and acceptance of GM foods. They found that Europeans had higher scores than Americans on an objective true/false test of textbook knowledge related to the science behind genetic modification, but they were less approving of GM foods when compared with the American sample. This suggested a negative relationship between scientific knowledge and approval. However, the researchers examined three additional knowledge items focusing on beliefs in fictional threatening images related to GM foods, such as "GM animals are always larger than non-GM animals." The American respondents were more likely than their European counterparts to recognize that these images are false and thus scored higher on this scale of knowledge, suggesting a positive relationship between knowledge and approval of GM foods. The clear implication is that the link between knowledge and approval of new technologies has as much to do with the *kind* of knowledge as the amount of knowledge understood by individuals.

In addition, the strength of the relationship between knowledge and approval of new technologies is often modest. In a study of the relationship between knowledge and approval of GM foods using items identical to those used by Gaskell et al. (1999), Cuite, Aquino, and Hallman (2005) found that although increased knowledge was significantly related to higher levels of approval, the relationship between the two was weak. Together, a model including several measures of knowledge, including their scores on textbook knowledge about the basics of genetics and biotechnology, awareness of GM foods in the marketplace, and self-assessed knowledge, plus demographic variables, explained only 8 percent of the variance in approval ratings. This suggests that while knowledge appears to be related to approval, the practical significance of this relationship is open to question and may not be as important a factor in influencing opinions about GM foods as it is often assumed to be.

People Cannot Simply Be "Educated" into Accepting New Technologies

Unfortunately, many efforts to gain public acceptance of new technologies are based on the faulty premise that if people understood more about the science behind a technology, they would come to understand and share the viewpoints and conclusions about the technology reached by the experts. This knowledge deficit model (Wynne and Irwin 1996; Einsiedel 2000; Hansen et al. 2003) assumes that if people just knew the facts, they would reach the right conclusions or make the right decisions.

It is easy to understand why the knowledge deficit model holds such an appeal for scientific and technical experts–the model takes for granted that people fundamentally approach the world just like experts; it's just that lay people are not as intelligent, educated, or well informed. It also presumes that the conclusions reached by experts are consistently correct and that those of non-experts are fundamentally wrong because lay people do not have the required scientific knowledge, technical experience, or understanding of the issues to make proper decisions. But, the model assumes, given the requisite knowledge, experience, and understanding, lay people can develop the expertise they need to "correctly" evaluate technologies and reach the "right" conclusions; that is, the same conclusions already reached by the experts. Therefore, the solution to public acceptance of new technologies is to "educate" lay people to fill in the gaps in their knowledge and to lead them to adopt the "informed" views of the experts.

Unfortunately, research clearly shows that people are more complex creatures and that merely providing information rarely changes their attitudes or behaviours (Weinstein 1988). This should come as little surprise, as the ineffectiveness of this approach is regularly confirmed in our everyday experience. If "simply providing the facts" were really effective in persuading people to adopt a particular point of view about technologies or to change their behaviours toward them, people would wear seat belts in their cars, install carbon monoxide detectors in their homes, and avoid trans fats in their diets. Moreover, if this strategy of "informing people" were successful, people would all drive the same kinds of cars, use the same kind of mouthwash, and wear the same brand of athletic shoes. But, clearly, this kind of universal consensus does not exist. If it did, there would be no need for advertising, politics, self-help books, or late-night televangelists. There would also be no reason to read this book.

Yet, although people are very rarely swayed by mere presentation of scientific facts, experts continue to labour under the illusion that such efforts *must* be effective. The problem, of course, is that although people *do* use scientific information in their decisions about the risks and benefits of technologies, it is not the *only* information they use when considering a risk. So, although scientific knowledge does seem to have an impact on attitudes about new technologies, the relationship is often modest, and non-linear (Sturgis and Allum 2004).

There are likely several reasons for this. Because most people do not have extensive backgrounds in scientific disciplines, some scholars suggest that the influence of scientific knowledge on attitudes may be directly related to the extent to which scientific information is seen as consistent with personal experience (Jasanoff 2000) and with the specific worldviews, core beliefs, or values held by individuals (Slovic and Peters 1998).

The impacts of scientific information may also be moderated or contextualized by other types of knowledge that may include an understanding of how scientific expertise is developed and how science is organized, financed, and controlled. Each can have an effect on trust in the "truths" developed by science (Wynne 1992).

Finally, people may have concerns about a technology that go beyond those typically addressed by science (Hansen et al. 2003). How scientific information is incorporated into how people think about the risks and benefits of a new technology can be strongly influenced by cultural norms and assumptions about what is good, pure, and useful (Douglas and Wildavsky 1982). As such, as Peters (2000) suggests, there are various reasons people may lack faith in, disagree with, or fail to follow the science-based recommendations made by experts that have little to do with a lack of understanding of the science. Indeed, outside the areas of their own expertise, even experts use sources of information other than science to make decisions.

Still, this does not mean that we should abandon efforts to help people understand the science behind new technologies. At the same time, however, we should discard the idea that it is possible to "educate" people into accepting them.

People Are More Interested in What Technology Can Do Than in How It Works

We do need to explain some of the science behind new technologies, because such an understanding may ultimately be necessary for people to separate fact from fiction as proponents and opponents of the technologies attempt to persuade the public to adopt their positions. The problem is that communications about new technologies are often based on an expert model of what people *need* to know rather than on what people *want* to know. Often, this strategy begins with having a group of experts assess the facts they believe non-experts need to know to understand the science behind the technology. The second step is usually an attempt to translate these scientific facts into simple language and graphics so that non-experts can easily understand them. The last step is usually to create a set of communications materials to be distributed to as many people as possible.

Unfortunately, communication strategies based on an expert model are usually unsuccessful. One reason is that experts tend to overestimate what ordinary people know about science. In the case of communications about GM foods, many educational efforts assume that lay people have a level of understanding of basic biology that is not generally borne out by surveys of the public (Hallman et al. 2002). (For example, in a national survey of 1,203 Americans, half of those interviewed said they had never heard about traditional crossbreeding methods, even when those methods were described to them in simple terms. In addition, despite virtually all the varieties of fruits and vegetables available having resulted from centuries of traditional crossbreeding, 61 percent of respondents said they had never eaten a fruit or vegetable produced using traditional crossbreeding methods; another 11 percent indicated that they were not sure.) Efforts designed to convince people that genetic modification techniques are simply a faster, more versatile, and more precise way of achieving the aims of traditional crossbreeding are likely to have little impact. The lesson is that some efforts to teach people about new technologies are not successful simply because many people are not able to put the new information into any meaningful context. These efforts fail because they try to build on a foundation that just does not exist.

Some efforts to educate people about new technologies fail because the experts who design them discover that many people lack the necessary foundation to understand the complex scientific ideas and information the experts want to get across. The experts therefore attempt to remediate the situation by insisting on efforts to build such a foundation for their audiences, block by boring block. These attempts fail because, while lay people *say* they are interested in science, what they are often more interested in is the excitement of new discoveries and their potential impacts, rather than in learning about the rather tedious *details* of the science (Harp and Mayer 1997, 1998).

For example, in a national survey, Hallman et al. (2004) asked respondents to "imagine that we designed a television show especially for you on the topic of genetically modified foods." They were then asked to rate their interest in each of thirteen shows using a scale of one to ten where one represented "not at all interested" and ten represented "extremely interested." Most respondents expressed interest in all the topics presented, giving each median ratings of eight or better on the ten-point scale. However, they indicated the greatest interest (median ratings of ten) in the two stories related to the potential health consequences of the technology: "the potential dangers of eating GM food on personal and family health" and "whether anyone has ever gotten sick from GM foods." They showed somewhat less interest in stories about whether genetic modification would have an effect on the cost of food for consumers or on farmers' costs of producing food, the companies involved in the production of GM foods, which foods or brands of food specifically *do not* contain GM ingredients, and "the science involved in the genetic modification of food products." Each of these hypothetical shows was given a median rating of eight on the scale. The results suggest that although Americans *are* interested in the science behind GM foods, it is not necessarily their first interest. Yet, many efforts to communicate about GM foods focus predominantly (or exclusively) on how the technology *works,* rather than on what the technology *means* for people.

The Risks and Benefits of New Technologies Matter

Even though many people have difficulty understanding the scientific details of how a technology works, they are often interested in, and better able to grasp, the costs, risks, and benefits of these technologies. As a result, there can be substantial differences in the way people think about new technologies in the abstract and the way they think about specific applications of that technology.

For example, the technology behind genetic modification is an unfamiliar and relatively abstract concept, lacking any real context for most Americans. Because they do not understand the technology and do not feel particularly qualified to evaluate its risks or merits, people's first reactions to the technology itself tend to be rather negative. Yet, people are often readily able to understand, and contextualize, the specific benefits of products created through the use of GM technology and so respond quite positively to the idea of using genetic modification to create products with useful characteristics.

For example, Hallman et al. (2002) found that when asked about GM technology in the abstract, only 58 percent of Americans say they approve of the use of genetic modification to create new kinds of plants. Yet, 88 percent say they would approve of the use of genetic modification to create rice with enhanced vitamin A to prevent blindness, and 85 percent say they would approve of the use of the technology to create more nutritious grain that could feed people in poor countries. Similarly, when asked in the abstract, only 28 percent of Americans say they approve of the use of genetic modification to create hybrid animals. Nonetheless, 84 percent say they would approve of the use of genetic modification to create hormones such as insulin to help diabetics, and more than three-quarters of the public (76 percent) say they would approve of the use of the technology to create sheep whose milk can be used to produce medicines and vaccines.

However, people's approval of GM products is not entirely based on altruism. They also tend to approve of GM products from which they might benefit personally. Indeed, nearly three-quarters of those surveyed (74 percent) said they would also approve of the use of genetic modification to create less expensive or better tasting produce, and more than three-quarters (76 percent) said they would approve of "genetically modified grass that you don't have to mow so often." In fact, many researchers have attributed the lack of acceptance of GM foods around the world to the lack of perceived personal benefits to consumers (Hoban 1998).

The large difference between the way people think about GM technology in the abstract and their perceptions of specific products is illustrated by Hallman et al. (2003). Early in their national survey, they asked respondents whether they approved or disapproved of the use of GM technology to create new plant-based and animal-based food products. Later in the survey, the respondents were asked whether they would *buy* GM food products with particular beneficial characteristics. Matching the answers of individual respondents, it was clear that many who initially said they disapproved of the use of the technology later said they would purchase products of that technology with appealing personal benefits. For example, of those who initially disapproved of plant-based GM food products, 26 percent later said they would purchase such products if they had less fat and 21 percent said they would if it tasted better than ordinary food.

GM foods with environmental benefits were also looked on favourably. About one-third (31 percent) of those who initially disapproved of creating plant-based GM food products said they would be willing to buy a GM product grown in a more environmentally friendly way than ordinary food. Moreover, 44 percent of those who initially disapproved of plant-based GM products said they would be willing to purchase them if they contained less pesticide residues than non-GM food.

This expressed preference for the use of GM technology to reduce pesticide residues in food is particularly interesting since reductions in the use of pesticides is a main benefit currently conferred by existing GM crops (Economic Research Service 2005). However, the reduced use of pesticides on crops is an advantage of GM technology that is not marketed specifically as a direct benefit to consumers. Instead, it is advertised as being better for the environment and for the farmer's bottom line.

Not All Applications of the Technology Are Seen as Equivalent

The large difference between the way people think about GM technology in the abstract and their perceptions of specific products suggests that people may judge the merits of the products of genetic modification on a case-by-case basis, considering the characteristics of specific products of biotechnology rather than categorically deciding that all biotechnology is good or bad. Therefore, just because consumers find one GM product to be acceptable or even desirable does not mean that they necessarily approve of the underlying technology, or of its application to other products. Unlike in the information-technology sector, there is almost certainly no "killer application" in the foreseeable future that will drive consumer acceptance of the basic technology behind GM foods. Therefore, one should be cautious in concluding, for example, that "due to the importance of rice in the developing world and the significant part played by the public sector in providing new rice crop technology, the drive to apply GM technology to rice may well result in faster acceptance of the technology in rice than would be the case for other crops. Rice therefore has the potential to act as a catalyst to the wider adoption and acceptance of GM crop technology" (PG Economics 2002, 1).

Indeed, most studies of public opinion concerning genetic modification confirm that consumers express a hierarchy of approval. That is, they are much more willing to approve of the use of GM technology on plants than on animals, more likely to endorse the use of the technology within rather than across species, and least supportive of the use of GM to alter humans in any way (see Gaskell, Allum, and Stares 2003; Pew Initiative on Food and Biotechnology 2004, 2005). Indeed, many people who say they favour using genetic engineering to create new varieties of plants do not approve of its use to create new breeds of animals. As has been suggested, "people see a real difference between using biotechnology to create better beef and using it to create better beefsteak tomatoes" (Hallman 1995).

Perceived Motivations Matter

Although people may ultimately be interested in the mechanisms that underpin new technologies, many will also admit that because the technical issues involved are so complex, they have a difficult time using this information to make judgments about the risks or the safety of the technology. They must therefore rely on the conclusions reached by those specialists who do have the requisite expertise to evaluate the merits of the technology. Because they lack the ability to interpret the technical information, it is not surprising that many people have less interest in the particular details about the science and technology than in specific details about the scientists and technicians involved. They want to be able to trust that the people behind the technology are using common sense and are making decisions that will appropriately protect the well-being of both people and the planet.

The question of whether those in the scientific community, the food biotechnology industry, and government regulators can be trusted to protect consumers and the environment from unsafe products features prominently in the debate over consumer acceptance or opposition to GM foods (Lang and Hallman 2005). Hallman et al. (2002) found that three-quarters (74 percent) of Americans believe that strict regulation of GM technology and products is needed. Yet, most were skeptical that scientists and the companies involved with food biotechnology have sufficient motivation or competence to protect the public from potentially adverse effects that might arise from the use of genetic modification (Hallman et al. 2002).

Although People Must Rely on Experts to Evaluate the Science, They Still Want to Be Involved in Decision Making

Although most Americans seem to know very little about the science of genetic modification, and many who are well informed will concede that the issues are so complex that they have a difficult time reaching conclusions on their own, they are reluctant to relinquish their involvement in decisions regarding the technology. For example, only one-quarter of Americans agree that "decisions about the issue of genetically modified food are so complicated that it is a waste of time to consult the public on this subject" (Hallman et al. 2002).

Gaskell et al. (2005) reported the results of social surveys in the United States, Canada, and the European Union, examining who the public thinks should make decisions about science policy and on what criteria such decisions should be based. They found that given a choice between having decisions about technology based mainly on the views and advice of experts or on the views of average citizens, nearly three-quarters say they would prefer that the views of experts guide such decisions. Moreover, when asked if these decisions should be made on the basis of scientific evidence or on the basis of moral or ethical considerations, two-thirds preferred that they be guided by scientific principles. The responses to these questions permitted the division of the public into four groups reflecting different preferred principles of governance over technology. The results showed considerable consistency in the attitudes of respondents across the three jurisdictions. About half of the respondents in each country were classified as "scientific elitists" preferring that decisions about technology be guided by expert advice based on scientific evidence. In contrast, about one in five were categorized as "moral elitists" preferring that such decisions be made on the basis of expert advice using moral and ethical criteria. Between 10 percent and 14 percent were identified as "scientific populists" opting for decisions based on the average citizen's views of the scientific evidence, and about 15 percent were tagged as "moral populists" preferring that decisions be based on the average citizen's views of the moral and ethical issues.

Thus, while about half the populations of the United States, Canada, and Europe appear to endorse the status quo regarding the governance of technology (experts making decisions based on scientific evidence), the other half do not seem particularly content with the current state of affairs. Rather than leave such important decisions to be made by unknown experts (who may or may not be trustworthy) on the basis of science that much of the public does not fully understand, they would prefer that decisions about technology be influenced by some combination of moral and ethical principles shared by average citizens.

What is interesting about this is that it suggests that people make some implicit assumptions about the ability or inability of average citizens to understand science and the ability or inability of scientific experts to understand ethics and morality. Yet, while they may question the ability of average people to understand science and the ability of scientists to understand ethical and moral issues, the assumption seems to be that scientific experts are uniquely qualified to judge science, but that average people are perhaps better qualified to judge ethics and morality. So, in deciding who should govern science, the choice comes down to "Although I assume that they are competent to understand the science, do I trust scientific experts to reflect the values of society?" versus "Although I trust average citizens to reflect the values of society, do I believe that they are competent to understand the science?"

Given that the scientific populists make up the smallest group identified in the United States, Canada, and the European Union, the answer to the second question appears to be no. Average citizens do not appear to judge each other as understanding enough about science and technology to have sufficiently informed views.

In the case of GM foods, this may be because each respondent perceives himself or herself to be an average citizen, and because they judge themselves as not well informed enough about GM technology to make decisions about it, this must therefore be true of all average citizens. In contrast, some people may consider themselves to be particularly knowledgeable about the technology, with expertise on the subject well beyond that of the average citizen. Realizing the complexities involved and the knowledge and effort necessary to understand them, these people may realistically decide that average citizens do not have the time, scientific background, or proclivity to undertake what is required. Either way, people do not seem to be particularly optimistic about the abilities of their fellow citizens to participate in complex decisions about technology.

The remaining question then is, how are people to decide whether scientific experts share the same values, morals, and ethics as average citizens, and how can they be confident that the decisions made by these strangers will be consonant with societal wishes? The GM debate suggests that those in the scientific community have a responsibility to deliberately counter the view that science and ethics are incompatible.

Consensus about Which Problems Are Worth Solving Is Important

Most people are decidedly *not* anti-technology; the public wants science and technology to solve problems. The issue is that they want some say in deciding which problems are worth solving and whether the solutions proposed are acceptable. Indeed, the final and perhaps most important lesson to be drawn from the GM food experience is that, for new technologies, success is not about attracting public trust and consent for an agenda already established by science, scientists, industry, or government officials but, rather, achieving some shared societal vision of what needs to be done and how. Rather than simply being seen as obstructionists who need to be convinced of the acceptability of new technologies, perhaps members of society should be seen as *investors* who want to have some influence on the direction of development.

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