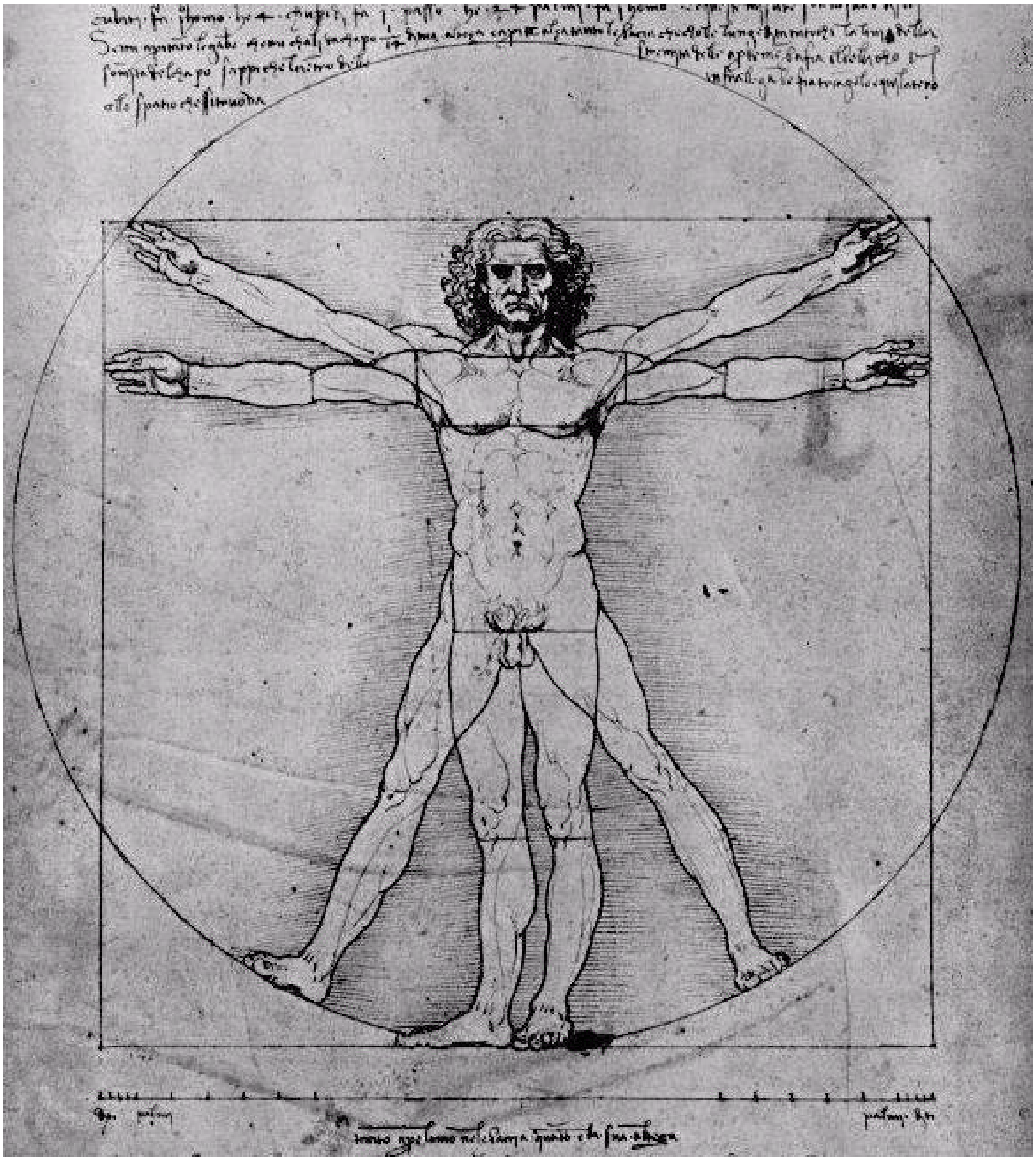
Key Lessons from the History of Science and Technology: Knowns and Unknowns, Breakthroughs and Cautions



Office of the
PARLIAMENTARY COMMISSIONER FOR THE ENVIRONMENT
Te Kaitiaki Taiao a Te Whare Päremata

March 2001

Key Lessons from the History of Science and Technology: Knowns and Unknowns, Breakthroughs and Cautions

Office of the
PARLIAMENTARY COMMISSIONER FOR THE ENVIRONMENT
Te Kaitiaki Taiao a Te Whare Päremata

March 2001

PO Box 10-241, Wellington, www.pce.govt.nz

Author
Wren Green
Director, EcoLogic Conservation Consultants

With assistance from
Helen Beaumont
Ronda Cooper
Sarah Ireland
Bruce Taylor

Layout
Megan Chisholm

The report is available on the PCE's website: www.pce.govt.nz

Bibliographic reference
Parliamentary Commissioner for the Environment 2001: *Key Lessons from the History of Science and Technology: Knowns and Unknowns, Breakthroughs and Cautions.* Parliamentary Commissioner for the Environment, Wellington.

ISBN: 0-908804-97-0

Preface

The origins of this paper stem from a number of concerns I have about the way New Zealand is approaching the application of genetic sciences. In my study[1] of New Zealanders' perspectives on the possible use of genetic engineering (GE) in biocontrols for possums, our worst animal pest, it became evident that there are differences in attitude between some science sectors and the New Zealand public. While there was widespread recognition of the potential benefits of GE, there were also deep concerns about the extent of the unknowns with this new technology, about possible side effects, and unforeseen impacts particularly on the natural environment. There was a view that the whole story might not be being told by developers of some GE products or technologies, and that there was insufficient precaution in the way GE products were being developed. I and my team were constantly reminded of past undesirable side effects emerging from new scientific developments and technologies. There was also a general belief that in the 21st century we should have the collective wisdom to avoid the kinds of mistakes made in the past.

But have we? When I canvassed public agencies and science organisations holding "Interested Person" status with the Royal Commission on Genetic Modification, I found that no one intended to provide detailed information to the Commission on the lessons that might be extracted from the applications of earlier sciences and now applied to genetic modification. There was agreement by some that this would be useful, but it was not a priority for them.

I believe it is important that we do learn from the past, particularly when the science in question enables humanity to manipulate the very basics of life on this planet. This capacity is fundamentally different from any other science. The potential for unknown outcomes is enormous, particularly once new genetic constructs are able to flow freely through ecosystems. This does not mean that we should stop developing applications of genetic sciences to answer the needs of people and the ecosystems that sustain them, but it does mean that we cannot proceed with applications of this science in the way we have with most past sciences and technologies. The past model - enthusiastic early applications, opposition to calls for caution, then modifications when undesirable effects emerge - is not appropriate in the 21st century.

I hope this collection of stories about science and resultant technologies will help us all reflect on how we can learn from past experience. Having reflected, I trust you will then contribute to the ongoing debate, and the development of processes aimed at ensuring that application of genetic sciences to New Zealand's future will be safe and ecologically sustainable.

Dr J Morgan Williams
Parliamentary Commissioner for the Environment

[1] *Caught in the Headlights: New Zealanders' Reflections on Possums, Control Options and Genetic Engineering.* Parliamentary Commissioner for the Environment, October 2000.

Table of Contents

"Optimism is a good characteristic, but if carried to an excess it becomes foolishness…"
Theodore Roosevelt, Annual Message to Congress, 1907.

"If there's more than one way to do a job and one of those ways will end in disaster, then someone will do it that way."
Captain Edward Murphy Jr., US Air Force, around 1950.

"A particularly unfortunate consequence of too narrow a view is the dangerous phenomenon of unrestrained technological optimism."[1]
Scientific American 1971.

1. Purpose of the Paper

This paper is intended as a contribution to New Zealand's thinking about how we manage genetic sciences and the applications that flow from it over the coming decades. It was commissioned by the Parliamentary Commissioner for the Environment because he believed there was merit in looking for lessons in the history of applications of sciences and technologies as New Zealand grapples with the promise, great unknowns and widespread community concerns surrounding genetic sciences, genetic engineering and genetically modified organisms.

Much has been written about the histories of science and technology. This paper will selectively cover only a small part of this large canvas of human endeavour. Filled as it is with major triumphs of intellect and advances in human welfare, a look backwards also reveals, from time to time, a more disturbing picture.

There are instances where the early claims of major benefits from a scientific or technological advance, with their attendant benefits, have been spectacularly justified – at first. Only later have unexpected and unanticipated negative consequences emerged. Sometimes these consequences have been severe enough to seriously undermine the original enterprise. On other occasions complex surprises have yielded new knowledge and made it possible, thanks to these new understandings, to refine the technology concerned. The outcome can then be safer use, usually with more prudence and care once the inherent limitations and risks of the technology are better understood.

Examples from a wide range of disciplines and technologies over the past century will be used to illustrate and expand these points. They also show that sometimes early claims of benefits are dangerously devoid of an adequate understanding of the underlying mechanisms. Proponents of new technologies can be slow to respond to the surprises that later emerge. Shortcomings in the approach to risk assessment involving complex systems are also discussed. These highlight the need to recognise the limits to scientific knowledge and the need to adopt a broader integrative approach to managing complexity, one that allows for surprises and values ethical considerations.

[1] Introductory Essay in Man and the Ecosphere. Readings from Scientific American. 1971. Freeman and Co.

2. Transportation

2.1 The Titanic – a 'signal event'

The maiden voyage of the Titanic in 1912 was preceded by considerable hype. At the time it was the largest ship ever built. Widely described as "unsinkable", its owners confidently expected it to become the fastest trans-Atlantic liner of the period, as well as highly profitable for the White Star Line. For many, it was an icon of technological achievement for the prosperous Victorian era. The machine paradigm was supreme, responsible for the industrial might of Europe and the conquest of distance and travel on land and sea. The Titanic was to usher in a new century of even greater achievements as machine and man continued to dominate nature.

The sinking of the Titanic on 14 April 1912, with the deaths of fifteen hundred passengers and crew, became a "signal event" in the language of risk analysts. An aura of invincibility, and therefore safety, that was associated with the Titanic played a major part in the disaster. It was steaming at high speed, with inappropriate confidence from captain and crew, through waters that were well known to be notorious for sea ice. During the 1880s, fourteen passenger vessels had sunk from collisions with sea ice in and around that area and another thirty-four had been damaged.

After it struck the iceberg, belief in the Titanic's inherent safety fatally delayed the efforts to abandon ship, which added to the loss of life. Some adjacent ships that might have helped with the rescue interpreted the flares from the "unsinkable" Titanic as indicating a celebration, not a real emergency.

The consequences and dangers of technological pride that the Titanic episode represents led to major maritime reforms. New international regulations required lifeboat capacity for all passengers and crew. A series of international conferences called Safety of Life at Sea started in 1913. The International Ice Patrol was also established in 1913 in recognition of the serious risk to international navigation posed by sea ice in the heavily used North Atlantic ocean routes. Each new generation of ships has had to meet ever higher standards, including a maximum of 30-minute evacuation procedures for cruise ships.

Ocean cruises are now much safer than they used to be. The story of the Titanic illustrates the hidden catch of technological improvement which is the need for "enhanced vigilance"[2], a requirement that extends well beyond standards for cruise liners. Advanced technologies demand "repeated rituals" for safe operation. Failure to maintain these repeated rituals have had catastrophic consequences – the best known being incidents in nuclear power stations, one of the most advanced technologies that has been developed.

---

[2] Why Things Bite Back. Technology and the Revenge of Unintended Consequences. Edward Tenner. 1996. Alfred Knopf, New York.

2.2 From Karl Benz to mass motoring

The patenting by Karl Benz of the internal combustion engine in 1886, followed by Henry Ford's liberation of travel for the middle classes with his mass produced cars, started a treadmill of innovation, unexpected consequences, 'solutions' and surprises that continue today.

Unlike the Titanic, there was no 'signal event' to jolt reforms in a technology that was killing people in ever increasing numbers each year. Car accidents were small personal disasters. In 1950, when the automotive industry epitomised big business in the USA, seat belts were not mandatory, car designs still favoured fashion and profits over safety concerns, and efforts to improve safety standards were resisted. By this time mass motoring had profoundly affected urban planning, led to increased demands for petroleum, provided a significant source of urban air pollution, and required large inner city and rural areas for motorway construction.

In fact, "*the greatest surprise of motoring was the speed at which traffic clogged the roads, including freeways, built to relieve congestion..".*[3] The Washington Beltway was opened in 1964 with a declaration by the governor that it was "a road of opportunity". Yet 22 years later, a Washington Post reporter wrote: "*The dream turned to nightmare. The Great Belt tightened to the point where right now it resembles nothing less than a noose around the communal neck…*" In London the M25 motorway, a ring-road, was built for similar reasons to the Beltway. By the late 1980s, only three years after its completion, it had already exceeded its projected traffic for the year 2001.

Cars now have global consequences well beyond drivers frustrated by rush-hour congestion. The world's 540 million cars contribute to global warming gases, and are a significant cause of loss of habitats and croplands. Recent calculations[4] predict severe shortages of cropland (lost to roads) in populous Third World countries if governments continue to support car-centred transport systems. Yet there are alternatives. In the case of China, for example, Chinese scientists have proposed that state-of-the-art light rail systems, with buses and bicycles, would provide mobility for more people than a car-centred system as well as protecting vital croplands. In Britain "*it is widely agreed that current rates of traffic growth are manifestly unsustainable*."[5] It would have been impossible a hundred years ago, when the first cars were appearing on horse-dominated roads, to anticipate or predict the complexity of the social, environmental, political and economic issues spawned by the humble car.

2.3 Aviation advances

Like the development of mass motoring, passenger air travel has gone through periods of technological advance, accidents, and improvements as knowledge is gained as a consequence. Global air travel is now an immensely complex system from the design of more efficient long-range jets, to the sophistication of computer booking and baggage tracking

[3] Tenner, ibid, Page 264.
[4] Paving the planet: cars and crops competing for land. 14 Feb. 2001. Worldwatch Institute.
[5] Environmental Science for Environmental Management. Second Edition. T. O'Riordan (ed). 2000. Prentice Hall.

systems. Air travel is also now very safe – at least from catastrophic accidents. During the 1980s, passenger fatalities per million enplanements in the United States dropped from 0.42 to 0.18 and serious injuries to passengers fell from 0.25 to 0.07. [6]

The intense vigilance at each point in the aviation system shows how the recognition of the potential for disaster continues to promote changes and improvements. Much of the current safety that air passengers enjoy is linked to the public pressure and positive learning value that a large and visible catastrophe can have. The cause of each crash is thoroughly investigated and the lessons learned, be they metal fatigue, wind shear problems, faulty design features, or pilot training, are added to the growing body of knowledge. Multiple options are built into aircraft designs so that backup systems take over if one system or individual part fails.

There are indications, however, that a chronic danger associated with long flights might now be killing more passengers than the occasional fiery crash. In October 2000, the death of 28-year old Emma Christoffersen from deep-vein thrombosis at London's Heathrow Airport after a 20-hour flight from Australia, made headline news. Lesson: blood clots formed after long periods of inactive sitting can kill when they reach the heart or lungs.

It is clear that the actual extent of this problem is unknown. Figures from Tokyo Airport[7] revealed that 25 passengers died there from blood clots and circulatory problems in the past eight years and 100 to 150 passengers are treated for the syndrome each year. The closest hospital to Heathrow reported 30 air passenger deaths from deep-vein thrombosis in the last three years. Australian figures suggest that up to 400 people a year arrive at Sydney Airport suffering from the thrombosis.

Nor are the symptoms and deaths necessarily immediate. They may develop days after flying, making the task of assessing the real level of risk even more difficult. A Sydney doctor says he has been "urging airlines to carry out investigations into the condition for years."[8] The very success of modern aircraft design, which makes flights of 12 hours for 400 passengers routine, might be exposing us to an elusive chronic problem that is difficult to research and evaluate.

2.4 Supersonic technology

"*After long negotiations the British and French Governments have at last decided to embark on one of the greatest adventures in the history of aviation*".

Announcement of the Anglo-French deal, 29 November 1962.

From now on the British aircraft would be called Concorde, like the French one, and not Concord. The extra "e", he said, stood for "excellence, England, Europe and entente".

Anthony Benn, British Technology Minister, 11 December 1967.

6 Tenner, ibid, Page 20.
7 Reported in New Scientist. 10 January 2001.
8 New Scientist, ibid.

The prototype Tupolev TU-144 supersonic airliner is declared "Hero of the Soviet Union" for having reached Mach 2.
26 May 1970.

"One of the most exciting events in aviation history"
Announcing the first commercial flight of Concorde, 21 January 1976.

The Concorde took 13 years of development and testing before the first commercial flight in 1976. The costly technical challenges forced France and Britain to work on a joint programme, backed by billions of pounds and francs from state funds. The project was started during the decade that the USA declared it would have a man on the moon by 1970 (in response to the Soviet first of launching a satellite in 1957). This was the space-age version of the years preceding the Titanic; improvements in the human condition were optimistically and naively linked to the simple expedient of travelling faster. The Concorde was small and noisy, seating was cramped, it consumed far more fuel than conventional jets, but political egos and economic rivalries sustained the exercise.

The Soviet's "Hero", the prototype Tupolev TU-144, crashed at the Paris Air Show in March 1973, and with it the whole Soviet supersonic flight programme came to an end.

Only 16 Concordes were commercially produced (the last in 1980) and only 13 were operational when an Air France Concorde crashed in Paris in July 2000, killing all 113 passengers and crew. The lesson from this first Concorde disaster has been swiftly learned. In January 2001, it was reported that the fuel tanks would be strengthened with a special rubber lining to reduce the vulnerability of the fuel tanks to the type of external damage that caused them to explode in the July crash.

The symbol of British and French pride, Concorde represents a technology that owed more to national and technological aspirations than a genuine social or economic goal. It can be seen, in retrospect, as the qualitative dead-end of the technological search for speed in moving people. It remains an expensive example of a technology pursued for its own sake, despite the social, environmental and economic costs of doing so.

3. Chemicals and Materials

3.1 Asbestos

"Asbestos" is the name for several minerals that can be broken down into fibres. They are exceptionally strong, resistant to heat and have been incorporated into thousands of products (including insulation, roofing tiles and cladding, cement pipes, ironing boards, paint, cement board, brakes, clutches, fireproof clothing). They were first added to construction and consumer materials in the USA in the late 1800s, when they were promoted as a great scientific advance. Asbestos promised protection from fire and collision; manufacturers and consumers alike thought its fire-retardent properties would save hundreds of lives. Theatre owners proudly announced its presence on the large asbestos curtains designed to shield audiences from potential backstage fires.

But by 1920, medical articles had described an unanticipated danger of asbestos. When the strong thin fibres are inhaled or ingested they pierce soft body tissues, become embedded, and cause debilitating, often fatal diseases as the body tries unsuccessfully to break the fibres down. The clinical characteristics of asbestosis (scaring of the lungs, loss of lung function) were described in Britain in 1930 (along with the importance of educating workers of the hazards of exposure), and in 1934 the link between asbestosis and lung cancer was published. Mesothelioma is a rare form of cancer of the outer lung tissue and is solely linked to asbestos fibres. It only appears 15 to 35 years after exposure. Asbestosis usually takes 25 to 40 years to appear.

The growing knowledge of the health hazards of asbestos eventually led to a report by the US Department of Health and Human Services in April 1980, stating that "*evaluation of all available human data provides no evidence for a threshold or for a 'safe' level of asbestos exposure…*". In 1989, after 10 years of investigation, the Environmental Protection Agency issued a rule banning the use of asbestos in the manufacture of products. In 1991, much of this ban was overturned following a successful lawsuit by the asbestos industry.

It is now known that the dangers of asbestos can be minimised by improved mining, processing and handling techniques, and safer disposal methods. Meanwhile, lawsuits against asbestos companies continue in various countries. Demand for asbestos has fallen in western Europe and North America, but risen in eastern Europe and the Far East where cheap building materials are sought.

Asbestos, the 'solution' to local catastrophic accidents (fires and vehicle accidents) has created a chronic health hazard in many countries. In the USA, it took about 40 years from first use to medical recognition of the hazard. It was another 50-plus years before government took protective action, with strong opposition from asbestos companies. In New Zealand, asbestos waste was laid on farm tracks to deal with muddy conditions at a time when its hazardous properties were not appreciated. One asbestos dumping site in Manukau City was subsequently used for residential purposes. Local residents now have concerns over health issues. Claims for compensation and questions about the Council's liability in this matter have also been raised and have yet to be resolved.

3.2 Lead additives

Lead has been used in various applications for almost 3,000 years, including Roman drinking goblets. Yet its capacity to act as a neurotoxin has been understood for centuries. The history of lead additives in petrol is not, therefore, a story about a technological advance with totally unexpected consequences. Instead, it is an example of how powerful vested interests can continue to produce and sell a product despite existing and growing evidence of its negative impacts, even after a cheap and safe alternative is well known and widely available.[9] The use of lead additives has had ramifications that extend well beyond national borders.

By 1920, automotive engineers were looking for a way to increase the 'octane' rating of petrol to reduce engine 'knocking noises', which would enable engineers to design cars with higher compression in the cylinders. This would, in turn, permit greater power and fuel efficiency. Ethanol (ethyl alcohol) had already been successfully tested. It had the advantage of being plentiful and easy to make. But General Motors and duPont rejected the ethanol option. They wanted an additive they could control and profit from, especially one they could patent. (In 1920, duPont controlled 35.8% of GM stock.) In 1921, a GM research engineer discovered that tetraethyl lead (TEL) reduced 'knocking' in internal combustion engines.

Between the 1920s and 1986 when the federal government banned lead from petrol sold in the United States, the burning of petrol accounted for 90% of lead emitted into the atmosphere. Lead does not break down over time, unlike pesticides, waste oils and even radioactive materials. So most of the estimated seven million tons of lead burned in petrol in the United States remains – deposited in the soil, water, and in the bodies of living organisms. A study by the US Environmental Protection Agency estimated that as many as 5,000 Americans died annually from lead-related heart disease problems prior to the lead phase-out.

Yet TEL was recognised very early as a threat to health. In 1922, the US Surgeon General expressed his concern in a letter to the General Motors President. In 1926, a special committee cautioned that further studies would be warranted if leaded petrol became widespread. But for the next 40 years all research of TEL's health effects were underwritten by GM, Standard Oil, duPont and trade associations for the lead industry. This cautionary tale supports the independent regulation of industry, rather than relying on industries' own scientific assurances.

Worldwide, human exposure to lead may now be 300 to 500 times greater than natural background levels. Lead from car exhausts travels in wind, rain and snow, well beyond national boundaries. While the mean blood-lead level of Americans continues to decline, a chronic problem remains, and may even be increasing in eastern Europe and in many Third World countries where leaded petrol continues to be sold.

Lead additives in other products – food cans, solder in water pipes and particularly in paint – have also had major impacts on human health. Young children are particularly sensitive to low levels of lead as their nervous systems are still actively growing. As a neurotoxin lead can cause problems in brain development and is often an unrecognised cause of behavioural difficulties.

3.3 CFCs (Chlorofluorocarbons)

For over 50 years, from their discovery at the end of the 1920s until the 1970s, a group of compounds called chlorofluorocarbons (CFCs) were regarded as a miracle substance by the chemical industry. They were ideal

---

[9] Based on "The Secret History of Lead" by J.L. Kitman. March 20, 2000. The Nation.

for their first use in refrigerators - non-flammable, non-toxic, cheap to manufacture, easy to store, and chemically very stable. CFCs neither burn with oxygen or poison living things. An ideal propellant for spray cans, the first such product was sold in 1950. They were subsequently used as solvents, and in blowing foams of all kinds, from fire extinguisher foam to house foam insulation and the foam in disposable coffee cups.

The route that led to the realisation that they also destroyed stratospheric ozone, thereby dangerously increasing the levels of UV radiation reaching the earth, was a fortuitous and circuitous one, with links back to the Concorde and to space shuttles.[10]

In the 1960s, when the United States was still contemplating production of a large fleet of supersonic transport aircraft (SST), concerns were raised that water vapour released by lots of SSTs might alter the climate by reflecting sunlight before it penetrated the troposphere. This fear proved unfounded, but related research raised the question of what impact nitrous oxides (from the SSTs exhaust gases) might have on the ozone layer, since nitric oxide was known to scavenge ozone. At the time, there were optimistic plans for a fleet of 800 Boeing SSTs operating by 1985 to 1990. Congressional hearings in 1971 heard evidence that, based on this number of SSTs, there was a potential for ozone depletion and significant rises in skin cancer. This got the subject of human impacts on the atmosphere out in the open.

The SST debate was preceeded by an investigation by the National Aeronautical and Space Administration (NASA) into the potential impacts of numerous shuttle flights on the upper atmosphere as rockets boosted the shuttle into orbit. (NASA was then optimistically planning on 60 shuttle flights *per year*.) In 1972, NASA decided to use solid-fuel rockets, which release a number of gases including hydrogen chloride (HCl). NASA's 1972 environmental impact statement stated that most of the HCl would be deposited in the stratosphere, but concluded there was no significant environmental risk. *"Space scientists didn't realise that chlorine atoms were efficient ozone scavengers; chemists didn't know that the shuttle boosters would emit HCl."*[11] Many complex problems of cause and effect are not resolved until linkages are made between normally separate scientific disciplines. The CFC story is just one such example.

Subsequent research commissioned by NASA linked chlorine with impacts on the ozone layer, but the impacts from shuttle flights *per se* were not deemed significant. By 1974, a public that had been very concerned about possible links between SSTs and skin cancer took little notice of the discussions about the potential effects of space shuttles on the ozone layer.

Enter the spray-can. In 1973, about 2.9 billion cans, half the world total, had been filled in the United States. About half of these cans used CFCs to propel the active ingredient (paint, hair spray, insecticides, etc) out of the can. In 1974, three independent research teams in the United States (some with links to earlier NASA research contracts), published the results of research suggesting that chlorine released by the breakdown of CFCs in the stratosphere could significantly deplete ozone levels with subsequent

[10] The Hole in the Sky. Mans' Threat to the Ozone Layer. John Gribbin. 1988. Corgi Books.

[11] Gribbin, ibid, Page 35.

substantial rises in UV impacts. By the end of 1974, the issue was national in the United States, initiating the 'spray-can war' of 1975 and 1976.[12]

The US National Academy of Science (NAS) set up a detailed study into CFCs and their stratospheric impacts. In September 1976, it reported that even holding CFCs to 1973 levels would lead to long term reductions of 6-7.5% in stratospheric ozone, leading to 12-15% increases in UV radiation reaching the earth. Manufacture of CFCs for aerosol propellants in the US was subsequently banned in October.

It would appear that the environmental concerns won the spray-can war in the United States in the 1970s. World-wide CFC releases then fell for a few years. In the 1970s, most scientists had been cautious about the need for action and only called for a ban on non-essential uses of CFCs in spray cans.

During the 1980s, however, total emissions rose world-wide as CFC uses were diversified and other countries continued to use them as propellants. Also during the 1980s new evidence of damage came in, including a completely unexpected consequence of ozone depletion, the ozone 'hole' over the Antarctica. In addition to their destructive impact on stratospheric ozone, CFCs were now recognised as a serious contributor to greenhouse gas hazards, especially if total CFC levels continued to rise. Many scientists reacted swiftly and logically, calling for more draconian action, including reductions of up to 95% of all existing uses. In this new and wider context, the win that stopped spray cans in the United States had merely been a battle, not the war.

Eventually, international concerns led to the development of the Vienna Convention for the Protection of the Ozone Layer in March 1985, and its Montreal Protocol of 1987. Joe Farman, a member of the British Antarctic Survey who discovered the ozone hole in 1982, wrote in the New Scientist on 12 November 1987: *"…no one predicted these depletions. The lesson is plain: existing policies on the production of CFCs are based on a false premise – that we understand the processes controlling the ozone layer. The past few years has shown that we do not.*"[13]

Progress was made on the reduction targets in subsequent years as the evidence of damage mounted and substitutes became available. As a consequence, global production of CFCs dropped by 85% between 1986 and 1997.[14] Is the war on behalf of the ozone layer therefore 'won'? Not yet. Ozone recovery rates are slow, Antarctic ozone levels remain low, and CFC producers have managed to delay the phase-out until 2030. This is in line with demands of US business interests that air-conditioning units in buildings be allowed to run their full 40-year working lives.[15] Also, methyl bromide is now known to also deplete ozone. Unlike CFCs, it is used as a fungicide, especially in Third World countries who have successfully argued for its retention and modest phase out.

---

[12] Attacks on the findings were made by CFC manufacturers. The details are covered in: The Ozone War by Lydia Dotto and Harold Schiff. 1978. Doubleday Publishers.
[13] Gribbin,ibid. Page 148.
[14] State of the World 2001. Worldwatch Institute, Washington D.C.
[15] O'Riordan, ibid. Pages 500-502.

4. Energy Systems

4.1 The "Big Dam" syndrome

If one of the purposes of modern technology is to control Nature to harness power and energy, then big dams stradling large rivers are impressive visual icons of its success. Currently, there are some 45,000 large dams world-wide in operation, representing a global investment of more than $2 trillion.

"*From the 1930s to the 1970s, the construction of large dams became in the eyes of many synonymous with development and economic progress. Viewed as symbols of modernisation and humanity's ability to harness nature, dam construction accelerated dramatically. This trend peaked in the 1970s, when on average, two or three dams were commissioned each day somewhere in the world.*"
Final Report, World Commission on Dams. 16 November 2000.[16]

The World Commission on Dams (WCD) was the first global attempt to comprehensively and independently assess large dams in the light of recent experience and performance, and to look beyond their technical and economic considerations. Growing opposition to large dams led to the establishment of the Commission. Global estimates suggest 40-80 million people have been displaced by dams and 60% of the world's rivers have been affected by dams and diversions. The WCD concluded that while dams have made an important and significant contribution to human development, with considerable derived benefits, too often "*…an unacceptable and often unnecessary price has been paid to secure those benefits, especially in social and environmental terms…*" Too often in the planning process social and environmental impacts of dams had been "*disregarded or unanticipated*".

The WCD says it is necessary to "*break through the traditional boundaries of thinking and look at these issues from a different perspective….The key decisions are not about dams as such, but about options for water and energy development*."

The assessment of large dams revealed:

- A high degree of variability in delivering predicted water and electricity services.
- A marked tendency towards schedule delays and significant cost over-runs.
- Irrigation services have typically fallen short of physical targets and did not recover costs.

[16] The World Commission on Dams was established as an independent body in February 1998. The 12 members were chaired by Professor Kader Asmal, then South Africa's Minister of Water Affairs and Forestry. The WCD did a global review of the development effectiveness of large dams; assessed alternatives for water resources and energy development; and developed international criteria, guidelines and standards for the planning, design, appraisal, construction, operation, monitoring and decommissioning of dams. The summary report is available from: www.dams.org/report/

- Extensive negative impacts on rivers, watersheds and aquatic ecosystems, with irreversible loss of species and ecosystems.
- Limited success in countering the ecosystem impacts of large dams owing to lack of attention to anticipating and avoiding impacts, poor quality and uncertainty of predictions and difficulty of coping with all impacts.
- Pervasive and systematic failure to assess the range of potential negative impacts and implement adequate mitigation, resettlement and development programmes for the displaced.
- Social groups that bore the environmental and social costs of big dams often did not benefit from the water and electricity services, or economic benefits.

In looking at alternative technologies, the Commission also identified a wide range of options that would be better to use than conventional dams, with fewer negative social and environmental impacts. Small-scale options can have major benefits, especially in rural areas.

If the focus of the Commission had been purely on the technological cost and benefits of large dams then ‘solutions’ and decision-making approaches based on better ecological and engineering practices would have been predictable. But the WCD went further than that. It said that decisions related to water and energy development needed, in addition to technical input, to be put through the essential tests provided by the five core values of:

1. Equity
2. Efficiency
3. Participatory decision-making
4. Sustainability
5. Accountability

Thus, the Commission argued, “*The debate about dams is a debate about the very meaning, purpose and pathways for achieving development*.” This lead the Commission to a decision-making and policy framework that explicitly recognises the Universal Declaration of Human Rights and extends risk assessment in the planning cycle to the ‘rights at risk’. It states:

“*Risks must be identified and addressed explicitly. This will require the notion of risk to be extended beyond governments or developers to include both those affected by a project and the environment as a public good. Involuntary risk bearers must be engaged by risk takers in a transparent process to negotiate equitable outcomes. … Using a rights-and-risks approach will raise the importance of the social and environmental dimensions of dams to a level once reserved for the economic dimension.*”

4.2 Nuclear power

“*It is not too much to expect that our children will enjoy in their homes electrical energy too cheap to meter*.”

Lewis Strauss, Chairman, US Atomic Energy Commission, 1954.

"*Summer resorts will be able to guarantee the weather and artificial suns will make it as easy to grow corn or potatoes indoors as on a farm*."

David Dietz, science writer, 1945.

The technological dream of sources of unlimited power and control over nature reached its clearest expression in the push for electricity from nuclear power. Some popular predictions in the mid-1950s were pure science fiction: 'atomic power' would run a car on an engine the size of a fist; houses would be heated by uranium; 'atom-powered' aircraft would be able to remain aloft indefinitely, and so on. All of this helped to soften the negative images associated with nuclear weapons and the devastation caused by two atomic bombs dropped on Japan.

In 1953, President Eisenhower launched the "Atoms for Peace" programme. Addressing the United Nations on December 8, 1953 he proposed a programme, based on military stocks of uranium, "*to devise methods whereby this fissionable material would be allocated to serve the peaceful pursuits of mankind… A special purpose would be to provide abundant electrical energy in the power-starved areas of the world*."

But the reality behind this popular view of the United States' enthusiasm for nuclear power was more complex. Technical studies by both US government agencies and industry in the 1940s and 1950s were in stark contrast to the unduly optimistic official pronouncements. Many studies concluded that coal-fired electrical generating stations would be cheaper and warned of the many "technical difficulties" that would need to be overcome.[17] One Presidential report in 1952 (the Paley Commission) even anticipated oil shortages in the 1970s, was pessimistic about nuclear power, and called for "aggressive research in the whole field of solar energy".

That this, and similar advice was ignored, appears more closely linked to prevailing Cold War propaganda than any economic or environmental considerations of the cost of nuclear power.[18] Eisenhower's "Atoms for Peace" speech was part of this propaganda effort. As a consequence, massive expenditure was committed to an inherently high-risk technology, which was recognised as such at the time, and before other negative consequences of nuclear power generation had been recognised.

About 45% of the eventual installed nuclear capacity of about 100,000 Mega Watt Electric in the United States was ordered in four years, 1963-1967. "*The power plants were built with government-subsidized insurance and without practical assurance that critical safety systems would work*."[19] The major Government subsidy came in the shape of the Price-Anderson Act, which limited the liability of industry to $500 million. With the financial risks to industry effectively reduced, there was less incentive to adopt a

[17] The Nuclear Power Deception. U.S. Nuclear Mythology from Electricity "Too Cheap to Meter" to "Inherently Safe" Reactors. 1999. A. Makhijani and S. Saleska.

[18] The Chairman of the Congressional Joint Committee on Atomic Energy warned in 1953: "*the relations of the United States with every other country in the world could be seriously damaged if Russia were to build an atomic power station for peacetime use ahead of us. The possibility that Russia might demonstrate her 'peaceful' intentions in the field of atomic energy while we are still concentrating on atomic weapons, could be a major blow to our position in the world*." Quoted by Makhijani and Saleska, ibid.

[19] Makhijani and Saleska, ibid.

precautionary approach to the technology. Consequently, many studies and experiments into the safety of nuclear reactors that had begun in the 1950s were not completed before commercial reactors started being built in large numbers.

The basic safety flaws of the 1950s designs had been identified within a decade, but the designs were used anyway because of the heavy investment that had already been made in them. Furthermore, the very complexity of the technology makes it difficult to make qualitative improvements even as the risks become better known, because of the enormous cost associated with doing so. All that accidents such as the 1979 partial meltdown in the light water reactor at Three Mile Island in the United States actually achieved was an improvement in operating procedures; *the risk is reduced only to the extent that greater human vigilance is secured*. Three Mile Island also showed that the accident probabilities (and the risks) might be higher than originally estimated. Since then, safety improvements have been made to new nuclear plants based on operational experience, including passive safety systems to operate in the event of major malfunctions.

Yet the potential for catastrophic accidents remains. In 1986, the Commissioner of the US Nuclear Regulatory Commission noted that *"given the present level of safety being achieved by the operating nuclear power plants in this country, we can expect to see a core meltdown accident within the next 20 years, and it is possible that such an accident could result in off-site releases of radiation which are as large as, or larger than, the releases estimated to have occurred at Chernobyl."*[20] Severe accidents are more likely in the former Soviet Union, given the relatively unsafe reactor designs, poor construction materials used in reactor systems and the low investment in maintenance.

In addition to the threat of local catastrophic accidents, nuclear power plants have bequeathed the world a chronic problem that, after 40 years, still has no satisfactory solution. In the 1950s, the disposal of high level radioactive waste was not forecast to pose serious economic or political constraints on the development of nuclear energy. This was a forecast made in the absence of experimental or observational data. It was assumed that nuclear scientists would somehow solve the waste problem. One such 'solution' has been to re-process nuclear wastes to extract new fuels for nuclear power plants. This has generated additional problems including opposition associated with the waste shipments and an accident at the Japanese re-processing facility.

A great deal has been learnt over 40 years about the behaviour of different radioactive waste substances in the living world, revealing environmental risks that extend globally and over time, given the exceptionally long life of many high level waste products.[21] Complex and often harmful effects have now been identified - from strontium-90 in human milk, to the uptake of plutonium by ocean phytoplankton and by grazing animals through the food chain. These effects range from immediate tissue damage, to cancers and trans-generational genetic damage. Perversely, while the understanding of

[20] Quoted by Makhijani and Saleska, ibid.

[21] The half-life of strontium-90 is 28 years; 30 years for caesium-137; 24,400 years for plutonium. (The 'half-life' is the time for half of the radioactivity to decay.) Ten half-lives are required to reduce the radioactivity of a sample to one-thousandth of its original level.

these risks has increased, the total volume of nuclear wastes has grown significantly. Every four years or so, commercial nuclear power reactors create an amount of plutonium equal to that in the global military stockpile.

As custodians of arguably the most complex technology created so far, at least with respect to non-living systems, providers of nuclear power have not been able to reduce its risks to levels that are politically and socially acceptable in many countries, regardless of the economic costs and benefits. Nevertheless, some countries with limited natural resources to generate their electricity requirements have opted to rely on nuclear power.

4.3 Costly Optimism

Optimism in the face of uncertainty, or even the unknown, has been a feature of major undertakings of modern science and technology, quite aside from nuclear power initiatives. High expectations are conceived with what one analyst calls "giddy techno-optimism" suggesting there is a simple motivation behind the modern technological paradigm summarised as – if it can be made, it should be made. Management experts at the US Rand Corporation examined 52 major civilian projects, ranging in cost from $500 million to over $10 billion, and found the average cost over-run was 88%.[22]

The bigger and more innovative the project, the bigger the problems. One example is the US National Ignition Facility, aiming to construct the world's most powerful laser. Not knowing how to construct key parts of the laser facility when the project began, it grew in a decade from a $400 million proposal to a possible $4 billion effort - if it is completed. In the same period, NASA's space station project expanded from an 8-year, $3 billion US flagship to a $60 billion, 16-nation project that has been in the works for 16 years.

"*Even when costs and schedules are tightly controlled, the complexity of today's technical endeavours is such that a single mis-step can be fatal, as a recent string of failed Mars probes demonstrated. They came in on time, on budget, and were lost in space one after the other, because of simple math errors and programming glitches*."[23]

In 1993, the US Congress finally cancelled an $8 billion particle accelerator called the Superconducting Supercollider because of financial and engineering difficulties. In 1991, Congress scaled back the Strategic Defense Initiative (dubbed 'Starwars'), for which the research spending may have reached $60 billion, after Congressional criticisms of the initiative. However, this extremely complex technological proposal may receive increased US funding in the future.

Back in 1979, United States President Carter proposed the production of 2 million barrels per day of synthetic fuels (synfuels) by 1992, at an estimated total cost of $88 billion, to reduce US dependence of foreign oil imports. Oil production from shale and coal was not a proven technology, especially at that scale, and would have had enormous social and environmental costs. In 1980, Forbes magazine acknowledged that there were "some environmental

---

[22] Costly projects cast science in a harsh light. R.L. Hotz. 19 September 2000. Times science writer, Los Angeles Times.
[23] Hotz, ibid.

question marks" about the project (citing water availability and pollution), but concluded: "*So there are problems, but it seems incredible that the US, rich in coal and shale, would blow this opportunity to break the shackles the OPEC has imposed both upon our economy and upon our foreign policy*."[24] Synfuels did not become a major contributor to US fuel needs, as the full extent of the environmental and developmental costs became apparent.

Opponents to the Carter synfuel proposal quoted reputable studies (incl. Harvard Business School, National Academy of Sciences) arguing that cheaper, safer, cleaner, more effective alternatives existed through greater use of solar power and significant improvements in energy efficiencies and conservation.

5. Military Initiatives

5.1 Atmospheric Nuclear Testing

During the 1950s, the USA, USSR, and Great Britain carried out extensive atmospheric testing of nuclear weapons. As the tests were carried out data emerged on the consequences of these tests. Many of the radioactive products of the explosions were distributed far more widely around the globe, via their transport in the upper atmosphere, than had been expected. One such product, strontium-90, was taken up in human bone tissue raising concerns about its potential to cause cancers.

Writing in Scientific American[25] in 1959, Nobel Laureate George Beadle discussed the delayed effects of fallout and "the increasingly important hazards of the peacetime uses of radiation." While lamenting the statistical difficulties of detecting long-term genetic effects, (which prolonged the debate) he noted: *"From the beginning of man's experience with ionizing radiation he has consistently underestimated its hazards. In fact, the tendency has been to underestimate not only the effects of a given exposure but often the amount of the exposure as well."*

Beginning in the 1920s, doctors used x-ray radiation indiscriminately to treat many disorders, including teenage acne, tuberculosis, sore throats, chronic coughs and enlarged tonsils. One serious misuse of x-rays between the 1930s and early 1950s was to 'treat' enlarged thymus glands in infants and toddlers. Thymus radiation, at doses 10 to 50 times greater than current diagnostic x-rays, was used in the mistaken belief that enlarged thymus glands were a cause of cot deaths. In fact, the thymus is particularly active in infants in assisting the immune system. A 1985 study found that infants treated with radiation for 'enlarged thymuses' have a two-fold higher risk for developing benign and malignant tumours in areas other than the thyroid. It was the discovery of thyroid abnormalities in children on Rongolap Atoll who had been exposed to iodine-131 from fallout that showed how quickly radiation can concentrate in the thyroid and cause damage. As a result, the

[24] Forbes, 21 July 1980. Page 45
[25] Ionizing radiation and the citizen. G.W. Beadle. September 1959. Scientific American.

permissible limit of exposure to ionizating radiation was reduced to one-tenth of what had previously been accepted.

The effects of radiation from strontium-90 and carbon-14, two of the most biologically significant radio-isotopes from testing, had also been underestimated. After further years of testing, the accumulation of further data, and major public protests, atmospheric testing was banned as the known risks finally became environmentally and politically unacceptable.

5.2 Agent Orange

"Agent Orange" got its name from the orange-striped drums containing the herbicide that was sprayed over large tracts of Southeast Asian forest and about half of South Vietnam's arable land between 1962 and 1970 during the Vietnam War. Nearly 12 million gallons of the herbicide were sprayed during this time. It was a mixture of two commonly used herbicides of the time – 2,4,5T and 2,4-D. The spray programme was designed to eliminate cover useful to the North Vietnamese army or Viet Cong guerrillas.

At the time, the spraying of Agent Orange was a minor part of the total conflict. However, the impacts of the spraying are still felt through its subsequent effects on a generation that was born after the war had finished. The legacy of Agent Orange is due to trace amounts of substances, called dioxins, which are a by-product of the herbicide's complex production process. Dioxin concentrations in the herbicides were typically 0.05 parts per million in the products used in the United States. In Agent Orange, however, dioxin concentrations were up to 1,000 times higher.

A decade after the Vietnam conflict, a report by the US Environmental Protection Agency (in 1986) called dioxins "*the most potent carcinogen ever tested in laboratory animals*." More recent laboratory work has linked dioxins with birth defects, spontaneous abortion, and damage to the immune system. Dioxins are long-lived, persist in the soil and are taken up through the food chain ('bioaccumulate'). The full extent of the ecological impacts and damage to human health is, as yet, unknown. Some Vietnamese doctors have reported a rise in certain birth defects in sprayed areas. Immune deficiency diseases and learning disabilities also appear to be higher in sprayed areas.

The discovery of the toxic, long-term impacts of dioxin are a cause for concern, not only for people in Vietnam, but also for the populations of many countries where dioxins have been unintentionally produced and released as a result of organochlorine production, the bleaching of wood pulp, and the burning of municipal waste. In 1995, a report by the United Nations Environment Programme that inventoried emissions in 15 countries traced 7,000 kilograms of dioxin and furan (similar to dioxins) releases to incinerator emissions. Given the extreme toxicity of these substances, 7,000 kilograms is a significant quantity.[26]

Enough is now known about dioxins to ensure that everything possible is done to phase out their inadvertent manufacture completely. International steps to this end are underway (see Section 7.2)

[26] There are 210 known dioxins and furans. POPs Culture. A.P. McGinn. March/April 2000. World Watch.

6. Medical Advances

6.1 Handwashing in hospitals

Handwashing in hospitals is an example of a simple technological lesson being slowly learned. In some cases safety procedures are adopted slowly, even when a clear benefit to human welfare has been demonstrated. This resistance may be due to tradition and an unwillingness to accept a new way of behaving. Sometimes, however, there is also an element of self-interest at work. The history of handwashing is one such example. During the 19th century, women in childbirth were dying in alarming rates in Europe and the United States. Up to 25% of women who delivered their babies in hospital died from childbed fever (puerperal sepsis), which was later found to be caused by the bacteria *Streptococcus pyogenes*.

As early as 1843, Dr Oliver Wendell Holmes advocated handwashing to prevent childbed fever. He correctly believed that childbed fever was an infectious disease passed to pregnant women by the hands of doctors. However, his ideas were greeted with disdain by many contemporary physicians.

In the late 1840s, Dr Ignaz Semmelweis in Vienna provided clear evidence of the benefits of handwashing. He had observed that the mortality rate in a delivery ward staffed by medical students was up to three times higher than in a second ward staffed by midwives. Semmelweis noted that students were coming straight from lessons in the autopsy room to the delivery room. By ordering doctors and medical students to wash their hands with a chlorinated solution before examining women in labour he reduced the mortality rate in his maternity wards to under 1%.

These remarkable results were greeted with hostility. He resigned, and later had similar dramatic results at another maternity clinic. Despite this, when Semmelweis died in 1865 (of puerperal sepsis) his views were still largely ridiculed. Opposition continued into the 1880s, 40 years after Holmes had expressed his concerns. Scepticism finally gave way however, and handwashing is now an important, if low tech practice in the fight against infectious diseases.

Scepticism, however, was not the only problem that faced the advocates of improved hygiene. In 1910, Josephine Baker, M.D. started a programme to teach hygiene to child care providers in New York. Thirty physicians sent a petition to the Mayor protesting that *"...It was ruining medical practice by …keeping babies well*."

6.2 Thalidomide

In 1957, a new sedative drug was launched by West German pharmaceutical company Chemie Grunenthal called Contergan. It was widely prescribed for pregnant women and is now most commonly known as thalidomide. In 1961, a range of serious and often fatal birth deformities started appearing. When the clinical evidence became overwhelming that thalidomide was the cause, the drug was finally taken off the market. The final global impact of thalidomide was severe abnormalities in eight thousand children in 46 countries.

It was argued at the time that the animal tests done prior to release by Chemie Grunenthal had been superficial and incomplete and potential teratogenic effects on the human foetus had not been considered. As a consequence of the thalidomide tragedy there has been a marked increase in the number of animals used in testing new drugs. Also drugs are now specifically tested on pregnant animals in an effort to safeguard against possible teratogenic effects on the human foetus.

While it is reassuring that new drugs are subjected to greater scrutiny before release, the technique presumes that results of animal tests are transferable to humans. That model is not necessarily valid. Thalidomide was subsequently tested on numerous strains of mice, rats, rabbits, dogs, cats, guinea pigs, hamsters and eight primate species. Only at high dose levels were similar abnormalities found, and then only in one rabbit strain and primates.[27]

'Thalidomide' was the 'signal event' that showed the relevance of the precautionary principle to the testing of new drugs. Yet the differences between species in their reactions to different drugs make it clear that animal testing cannot be relied upon as a substitute for knowledge of the potential for adverse effects on humans. The thalidomide tragedy also shattered the widespread medical belief that the placenta acted as an impenetrable shield protecting the foetus from harmful outside influences. Not only was the placenta no barrier to the drug, it was apparent that the developing foetus could be severely affected by substances and dose levels that were readily tolerated by adults.

6.3 Antibiotics in medicine

Antibiotic – (substance) capable of destroying or injuring living organisms, especially bacteria.

Concise Oxford Dictionary

Penicillin was discovered in 1928. That lead to the development of a wide range of antibiotics that were instrumental in saving millions of lives that in the past would have succumbed to bacterial infections. These impressive successes suggested, at the time, that the miracle antibiotics might rid humankind of many dreaded diseases forever.

Yet scientists found that bacteria had the capacity to mutate and develop resistance to antibiotic drugs not long after the discovery of penicillin. The answer was to develop new drugs that superseded the old, at least for a while. Sometimes only minor variations were needed to existing drugs. So for decades the endless cycle of new drug – resistant bacteria – new drug, has continued. What is now of concern is the rapid rate at which resistant strains are developing and the emergence of 'super-bugs' that are resistant to a number of antibiotics. Companies are also finding it more difficult to develop new effective antibiotics. New diseases that are resistant to antibiotics and the resurgence of old ones have shaken public confidence. In April 2000, the New England Journal of Medicine reported the case of a 12-

[27] Referenced in: Drugs and Pregnancy – Human Teratogenesis and Related Problems. D.F. Hawkins (ed). 1983. Churchill Livingston.

year old boy from Nebraska who contracted a strain of salmonella that was resistant to 13 different antibiotics.

A significant part of the reason for the growing resistance is the overuse and misuse of antibiotics by doctors. "*The highest rate of resistant bacteria are found in middle-class suburbanites – precisely the people who demand antibiotics from their doctors whether they need them or not.*"[28]

While it is a complex problem, health care experts promote two relatively simple solutions to slow the development of antibiotic resistance. The first is for doctors to prescribe antibiotics far more judiciously. The second is for better public education about the dangers of overusing antibiotics. The latter includes avoiding antibacterial products (soaps, lotions, toys, laundry detergents, etc) which health care professionals say are unnecessary and increase the development of resistance.

6.4 Synthetic hormone disruptors

"*Use DES for all pregnancies…for bigger and stronger babies*."
Drug company ad, June 1957.[29]

"*Unless the environmental load of synthetic hormone disruptors is abated and controlled, large scale dysfunction at the population level is possible*."
The Wingspan Consensus Statement, 1991.[30]

The discovery that a wide range of chemicals that are now widespread in the environment [31] are capable of seriously disrupting the endocrine systems of vertebrates is relatively recent. Impacts observed in the field have been confirmed in laboratory studies where the biological mechanisms or interactions have been elucidated. These effects and their implications are quite distinct from the adverse effects of pesticides described in Section 7.4. Hormones, in minute quantities, play a crucial role in the development of vertebrate animals; they are the chemical messengers orchestrating such critical aspects of development as sexual differentiation and brain organisation.

Wildlife populations are subject to a wide range of adverse effects from these synthetic hormone disruptors. These include: dysfunction of the thyroid plus reduced fertility and hatching success in birds and fish; gross birth deformities in birds, fish and turtles; behavioural abnormalities in birds; feminisation of male fish, birds and mammals; and compromised immune systems in birds and mammals.

In 1938, long before these wildlife effects were reported, British scientists had announced the synthesis of a chemical, diethylstilbestrol (DES) that somehow acted in the body like natural estrogen. Leading researchers and

---

[28] Antibiotics in the food chain. S.Brownlee. 21 May 2000. The Washington Post.
[29] Our Stolen Future by T.Colborn, D.Dumanoski and J.P. Myers. 1996. Abacus. Quoted on Page 48.
[30] Full text is the appendix to Our Stolen Future, ibid. Page 251.
[31] These include a range of pesticides (insecticides such as DDT and its degradation products, herbicides, fungicides), some industrial chemicals (eg. certain PCB congeners, tributyl-tin, alkyl phenols (including PVCs)), some dioxins and furans, soy products and some metals (cadmium, lead, mercury).

gynaecologists hailed it as a wonder drug with a host of potential uses. Researchers quickly started giving DES to women with pregnancy problems in the mistaken belief that insufficient estrogen levels caused miscarriages and premature births. In the following decades doctors prescribed DES very widely to: suppress milk production after childbirth; alleviate hot flushes and other menopausal symptoms; treat acne, prostate cancer, and even for untroubled pregnancies as if it were a vitamin. Farmers in some countries used DES extensively to speed the fattening of chickens, cows and other livestock.

Yet in the early 1930s research had already shown that extra doses of estrogen given to pregnant rats produced abnormalities stemming from disrupted sexual development. The young female rats exposed to extra estrogen in the womb had structural defects of the uterus, vagina and ovaries; male young had stunted penises and other genetic deformities. These findings tended to be dismissed by the medical profession as irrelevant to humans since humans were widely regarded as unique.

Then between 1966 and 1969 an unusual cluster of extremely rare cancers (clear-cell cancer of the vagina) showed up in a Boston hospital. All the patients were women aged between 15 and 22 years old, although this rare cancer almost never occurred in women under fifty. In 1971, it was reported that seven of the eight young women treated for the cancer had mothers who had taken DES during the first three months of pregnancy. Subsequently, other studies linked DES to deformities of the reproductive tract of both sons and daughters whose mothers had taken DES. As with thalidomide, the *timing* of the DES exposure appears to be more important than the size of the dose. Taking DES after the 20^{th} week of pregnancy does not result in reproductive deformities in the children.

During the 30 years in which an estimated five million pregnant women took DES in the USA, South America and elsewhere[32], there was no understanding of the way that DES and other hormone mimics actually work.[33] The emerging understanding is that exposure to tiny quantities are sufficient to disrupt vital biological processes. Hormones circulate in the blood in the range of parts per trillion. Many of the hormonally active synthetic chemicals, such as the organochlorines, are present in higher quantities.

These effects bear no relationship to the usual models of chemically induced disease or cancer; they can impact on the second generation while leaving the mother healthy, and may not show up until the affected offspring reaches reproductive age. Since hormone systems do not respond to the classical dose-response model that is the underlying assumption of studies of toxic substances, conventional approaches to this problem have typically led to more confusion than enlightenment.[34]

---

[32] Our Stolen Future, ibid. Page 48.
[33] Synthetic hormone disruptors can act in a number of different ways. Some mimic hormones by inappropriately stimulating hormone-responsive genes. Others block the expression of hormone-responsive genes or change the quantity of natural hormones by affecting the rate at which the hormone is synthesised or excreted.
[34] Our Stolen Future,ibid.

Many uncertainties remain about the effects of human exposure to synthetic hormone disruptors. The hormone disrupting effects of DDT, the polychlorinated biphenyls (PCBs) and dioxin get most attention, which may only reflect the fact that few other hormone-disrupting chemicals have been studied in any depth.

7. Modern Agriculture

7.1 Antibiotics in agriculture

"*Now we are running out of medicines that work. It's time to stop squandering drugs as precious as antibiotics to reduce the price of meat by a few cents a pound.*"[35]

An accidental discovery in 1949 has further complicated the antibiotics story. A New York pharmaceutical factory had been dumping the leftovers from the manufacture of the antibiotic tetracycline into the adjacent river. Subsequently people noticed that downstream fish were larger than average and tests revealed that the antibiotic was acting as a growth stimulant.[36] This discovery, that animals fed low doses of antibiotics grow bigger faster, and on less food, gave American agriculture a major competitive advantage. The practice spread to other developed countries, particularly Europe.

Fifty years on, there is major concern about the role these low dose food supplements are playing in breeding strains of antibiotic-resistant bacteria. The practice of giving antibiotics in low but daily doses to entire herds or flocks, raises huge implications for developing disease resistance. One estimate is that 75% of the 92 million pigs in the US have food laced with antibiotics, as do about 6% of cattle, 25% of chickens and 50% of turkeys.[37] "*With every dose, animals are turned into walking petri-dishes, breeding strains of antibiotic-resistant bacteria.*" About 15% of all antibiotics used in the European Union (EU) member states go into animal feed – amounting to some 1,600 tonnes of antibiotics entering the human food supply via pork and chicken every year.

The EU has now banned about 20 antibiotics from use in animal feed and more are likely to be added to the list. When four of these antibiotics were added to the banned list in December 1998, the pharmaceutical industry responded that there was no justification for the ban. "*Farmers expressed their disappointment, claiming it could give an unfair advantage to farmers who use the growth promoting chemicals in livestock outside Europe.*"[38] Not all were opposed however. The ban was welcomed by the Consumers' Association whose spokesman stated the Association was pleased by the "*adoption [of the] 'precautionary principle' in a matter that had implications for consumer safety.*"[39]

[35] Brownlee, ibid.
[36] Brownlee, ibid.
[37] Brownlee, ibid.
[38] Europe bans farm antibiotics. 14 December 1998. BBC News.
[39] BBC News, ibid.

Adopting the precautionary approach is more difficult in the United States, given the lobbying power of the agriculture and pharmaceutical industries. In 1980, the Food and Drug Administration (FDA) lost its first attempt to stop the use of antibiotics as growth promoters in animals. Now, with the backing of the World Health Organisation it has proposed a ranking system for new and existing antibiotics according to their importance to human health. Only antibiotics which have little value to human medicine would be widely available to farmers.

These are all attempts to reduce the unnecessary risks that have now been revealed from the 50-year practice of using antibiotics for a non-essential, but economically attractive purpose.

7.2 Pesticides

"*In each of my books I have tried to say that all the life of the planet is inter-related, that each species has its own ties to others, and that all are related to the earth. …it is also the message of Silent Spring*."

Rachel Carson, address to the Women's National Book Association.

"*Pest-control is of course necessary and desirable, but it is an ecological matter, and cannot be handed over entirely to the chemists. The present campaign for mass chemical control, besides being fostered by the profit motive, is another symptom of our exaggeratedly technological and quantitative approach.*"

Julian Huxley, Preface to *Silent Spring*, published 1962.

"*In any large scale pest control program we are immediately confronted with the objection of a vociferous, misinformed group of nature-balancing, organic-gardening, bird-loving, unreasonable citizenry that has not been convinced of the important place of agricultural chemicals in our economy*."

F.A. Soraci, Director, New Jersey Dept. of Agriculture, 1962.

Almost 40 years on, it is hard for today's generation to appreciate the uproar caused by the publication of *Silent Spring*. The chemical and agricultural industries saw it not as a scientific challenge to their dominant position, but as a public relations problem. Like the sinking of the Titanic, it turned out to be another 'signal event' in our perception of risk; this time the risks incurred by the widespread and largely indiscriminate use of long-lived toxic pesticides.

In the 25 years prior to the 1960s there had been a proliferation of synthetic chemicals that were often cheaper to produce directly from oil instead of using other materials. A major class of synthetics relies on the ability of chlorine (a highly reactive element), to combine with carbon-based compounds. These synthetics are called organochlorines and around 11,000 organochlorines are in production.[40] The biggest category of organochlorines is plastics and of those, the most common is polyvinyl chloride (PVC).

Organochlorines also have two properties that are very attractive, both to chemists and to farmers with monocultural crops, which tend to be susceptible to pests. Organochlorines are very stable (they persist in living systems a long time) and they have substantial chronic toxicity, which means

[40] McGinn, ibid.

that while exposure over the short term may not be dangerous, long-term exposure frequently is. During the 1940s, several major organochlorine insecticides were introduced including aldrin, chlordane, dichlorodiphenyl trichloroethane (DDT), dieldrin, heptachlor and toxaphene. DDT proved to be spectacularly successful in World War II in controlling body lice and therefore typhus. DDT rapidly became a widely used insecticide in agriculture and forestry, and in public-health campaigns against disease-carrying insects, such as mosquitoes. Some countries with high rate of malaria argue that the public health benefits of DDT outweigh any long-term risks to the environment and they support the continued use of DDT.

A third and critical property of organochlorines is that they tend to be fat soluble, which means that they accumulate in living tissue (bioaccumulation). The implications of this property were discovered in the late 1950s in evidence gleaned not from the target insect species, but from non-target carnivores such as hawkes, eagles and gulls. In the United States and Europe, reproductive failure in these species became widespread, with dead embryos and ultra-thin eggshells that cracked prematurely. Scientists then sampled animals along the food chain and discovered that the long-lasting DDT was being concentrated as it moved up the food chain. One New York study of a marsh, for example, found that the plankton in the water contained 0.04 parts per million of DDT, minnows contained about 1 part per million, and scavenging birds (a ring-billed gull) contained about 75 parts per million.[41] This represented a thousandfold increase in DDT concentrations and in many cases was sufficiently high to kill the animal, or certainly inhibit reproduction.

The earlier work that had revealed the processes behind the unexpected global distribution of radioactive fallout particles now became useful in investigating dispersal patterns of pesticides. It was thus discovered that DDT had been spread globally through the atmosphere and washed out in rain. DDT and its breakdown products DDD and DDE, were found in most food webs, including in the fat of seals and penguins in Antarctica. Given the long life of organochlorine pesticides, these toxic organochlorines have remained in food chains and soils for decades after their use has been banned (at least in developed countries).

Although there had been earlier scattered warnings about the potential ecological risks of these pesticides, it was not until Rachel Carson documented the impacts of pesticides on individual species and ecosystems, their environmental accumulations, the appearance of pesticide-resistant pests, and the direct impacts on human health, that the issue became widely recognised and debated. Carson also argued for a greater emphasis on the biological control of pests as an alternative to a heavy reliance on pesticides.

Carson's call for "*prudent concern for the integrity of the natural world that supports all life*" aroused a generation to question the conventional wisdom of controlling pests with non-specific long-lived poisons and successfully challenge the propaganda of the chemical and agricultural industries. Forty years on, negotiations have just concluded on an international treaty to phase out 12 specific persistent organic pollutants (POPs), including nine

[41] Toxic substances and ecological cycles. G.M. Woodwell. March 1967. Scientific American.

organochlorine pesticides, polychlorinated biphenyls (PCBs), as well as the two groups of industrial by-products, dioxins and the furans.

This can be seen as a modest, but important beginning to apply the precautionary principle in a world that sees another 1,000 or so new compounds enter the chemical economy every year, either as 'intermediates' used to make other chemicals, or as finished products.[42] A rough estimate puts the number of synthetic chemicals in commerce between 50,000 and 100,000. The number in the environment is probably greater, owing to the presence of by-products (like the dioxins) and breakdown products, like DDD and DDE.

7.3 From large cows to small prions

"*Prion – a disease causing agent that is responsible for a variety of fatal neuro-degenerative diseases of animals and humans called transmissible spongiform encephalopathies (TSE)*"

Encyclopaedia Britannica

"*Public trust can only be established if communications about risk are frank and objective [and] in particular, there must be openness about uncertainty*."

Lord Phillips, in Report on BSE, 2000.

Prions (pronounced 'pree-on') cause four known human disorders including Creutzfeldt-Jakob disease (CJD). As nerve cells are progressively destroyed brain tissue becomes riddled with holes in a sponge-like, or spongiform, pattern. Other prion diseases include scrapie (in sheep), chronic wasting diseases in mule deer and elk, and bovine spongiform encephalopathy (BSE or 'mad cow disease'). For many decades, doctors incorrectly believed these diseases were caused by slow-acting viruses, so-called because of the very long incubation periods while the diseases develop.

Neither the existence of prions, nor the links between BSE and CJD, were known in the 1970s when BSE probably first appeared in British cattle. It was not until 1980 that the "proteinaceous infectious particle" (later shortened to 'prion') was identified. A prion is an aberrant form of a normally harmless protein found in mammals and birds. Unlike all other known disease-causing organisms they appear to lack nucleic acid, the genetic material that all other forms of life contain. The concept of an infectious particle that lacks nucleic acid is unprecedented in biology and much is still unknown about this unique particle.

The 16-volume report by Lord Phillips into the BSE crisis in Britain, published in October 2000, documents numerous errors of science, in policy formulation, and of political mis-perception of the "public interest". Commenting on the report, the Editorial in New Scientist (4 November 2000) said: "*Despite the vast scale of the report it contains only one truly important message: secrecy and paternalism make for bad science and bad government.*"

The BSE crisis dramatically demonstrates how a combination of poor science, false reassurances to the public, unnecessary delays in undertaking

[42] McGinn, ibid.

critical research and preventive measures, plus a lack of scientific and political openness, led to a major erosion of public confidence, not only in politicians, but also in the integrity and trustworthiness of scientists. That erosion of trust has spilled over into the debate on GM food in Britain. It will require all groups involved in biotechnology "to think again" about how they interact with the public and reach decisions.[43]

A very brief account of the major developments that finally linked BSE to variant Creutzfeldt-Jakob disease (vCJD) follows.[44]

In February 1985, the first cow died from spongiform encephalopathy (SE). In November/December 1986, BSE was recognised as a new cattle disease, but this information was placed "under embargo" and withheld from the public for six months. In October 1987, BSE was found to be a prion disease that the Phillips' report suggested arose as a spontaneous mutation in the prion gene in a cow or sheep in the early 1970s. (This point is still under scientific debate and investigation.) The new BSE prion would then have infected other cattle, silently and exponentially, through the common practice of rendering the remains of dead animals (including, unknowingly, those with BSE prions) into meat and bone meal (MBM) for use as a cattle feed. In this way thousands of cows were infected before the first diagnosis was made. (In the peak year, 1992, there were 36,680 confirmed BSE cases in British cows.)

The fact that BSE was spreading through the MBM cattle feed was recognised in 1987, but it was wrongly *assumed*, instead of being tested, that BSE was the bovine form of sheep scrapie. This is the spongiform encephalopathy that has been known in sheep for 200 years. Ten years passed before research to test this crucial assumption was commissioned. It was also wrongly assumed that since scrapie was not a problem for humans, then BSE would not be either.

There were repeated reassurances that 'beef is safe to eat' - made by two scientific advisory committees, Britain's Chief Veterinary Officer, Chief Medical Officer and politicians. The scientific community was slow to accept that only half a gram of infective material (primarily edible material scraped from the spines of cows) could infect a cow or sheep. Consequently, it was not until December 1995 that government banned the practice of mechanically recovering and using this meat. This was nine years after the recognition of BSE as a new disease. During this time, poor abattoir practices had allowed the spread of BSE to farms to continue and to enter the human food chain. A ban on using meat and bone meal (MBM) had been imposed in July 1988, seven years earlier and three months after this pathway had been identified.

In May 1995, the first person died from variant CJD. Two and a half years later, mice studies revealed evidence of the link between vCJD and BSE. By the time the Phillips' report was released there were 84 definite or probable

---

[43] GM foods in the UK between 1996 and 1999: comments on "Genetically modified crops: risks and promise" by Gordon Conway", J.R. Krebs, 2000. Conservation Ecology, Vol 4 (1): 11. [online: www.consecol.org/vol4/iss1/art11]

[44] The key findings and lessons identified in the Phillips Report are summarised in New Scientist. 4 November 2000. Pages 4-9.

cases of vCJD in Britain. Projected total deaths from the epidemic range from a few hundred up to 136,000 victims.[45]

Throughout the BSE saga, there was a tendency to issue reassurances to the public based on inadequate or inaccurate scientific knowledge. Lord Phillips called for a re-evaluation by government and the public of their expectations of scientists. "*Scientists were expected to provide all the answers when sometimes this was not their proper role*."

Much still remains unknown about BSE and the risks to other species, although it is now clear that BSE affects different species in radically different ways. Sheep are of particular interest. When BSE-infected meat is fed to sheep they develop a disease clinically similar to sheep scrapie. Meat from these sheep produces BSE in mice. This indicates that these sheep still have BSE which, unlike scrapie, is a potential human pathogen. Could such sheep infect humans with BSE while showing the clinical signs of scrapie? Since BSE in sheep spreads through the body, unlike in cattle, how safe is sheep meat?

7.4 Green Revolution – the social costs

"*The Green Revolution was quintessential positivist science and technology in practice.*"[46]

In the late 1960s, an international effort in plant breeding produced a number of high yielding varieties of rice. These far out-performed local varieties, but only so long as they were provided with high levels of fertilisers and pesticides. Farmers had to buy the whole technological package – improved seed, fertilisers and pesticides – often at considerable cost. Yet the rationale was disarmingly simple and persuasive. The new varieties responded superbly to fertilisers, and the pesticides guaranteed security against herbivores, diseases and weeds.

Although much genetic diversity was lost as hundreds of local strains of rice were eliminated, development agencies put considerable resources into this approach to boost rice production. The Green Revolution approach was widely applied and may now be supporting 2.3-2.6 billion people (43% of global population) in the Third World, while still heavily dependent on external inputs of water, fertilisers, herbicides and pesticides.[47] A further 1.9-2.2 billion people in the poorest regions remain largely unconnected to modern agricultural technologies.

Within 10 years of its inception, however, problems with the Green Revolution approach had emerged. New pests were requiring more use of pesticides and in some countries the large applications of fertilisers were reducing soil fertility. For example, in the Philippines the use of urea (a petroleum-based fertiliser) which lacked the sulphur present in traditional

---

[45] New Scientist, ibid. 4 November 2000. Page 9.

[46] The role of the small-scale farmer in preserving the link between biodiversity and sustainable agriculture. M. Whitten and W.H. Settle Pages 187-207 in Frontiers in Biology: The Challenges of Biodiversity, Biotechnology and Sustainable Agriculture. 1998. (C.H. Chou and K.T. Shao, eds) Academia Sinica, Taipei.

[47] Regenerating Agriculture: Policy and Practice for Sustainability and Self-reliance. J.N.Pretty. 1995. Earthscan Publications, London.

fertiliser sources led to sulphur deficiencies which limited production.[48] Problems with high levels of pesticide use led scientists to promote the concept and practice of Integrated Pest Management (IPM), seeking to reduce chemical inputs by promoting the use of natural enemies of the pest species.

Significant social problems also emerged. Although rice yields had clearly increased, this had come at a high social cost. Farmers had come under the control of fertiliser and pesticide cartels. Subsequently the oil crisis of 1973-74 led to world fertiliser prices quadrupling, far outstripping gains in rice prices. But with their dependence on imported petroleum-based fertilisers, rice farmers had few options. Even a World Bank assessment in 1980 of the social impacts of the Green Revolution in the Philippines was not very positive: "*Some of the benefits of the new technology were captured by small rice farmers in the 1970s, but a disproportionate amount has probably gone to landlords, farmers with irrigation, relatively large or progressive farmers, owners of inputs [pesticide and fertiliser companies] and creditors.*"[49]

Writing in the Indian context 10 years later Vandana Shiva was more critical: "*The Punjab is frequently cited as the Green Revolution's most celebrated success story. Yet, far from bringing prosperity, two decades of the Green Revolution have left the Punjab riddled with discontent and violence. Instead of abundance, the Punjab is beset with diseased soils, pest-infested crops, waterlogged deserts and indebted and discontented farmers.*"[50]

New studies suggest that 'green' agriculture is being redefined in the Third World. A new report[51] into sustainable agriculture in 52 countries says that significant gains in crop yields were achieved by deliberately lowering man-made chemical inputs, while maximising natural inputs. Plants that fix nitrogen in the soil replace fertilisers and natural enemies of pests replace pesticides. The most widespread 'new' technique is farming without ploughing. In Argentina a third of fields are now left un-ploughed and farmers get rid of weeds by planting off-season crops that kill them. Soil quality is improving, as are crop yields.

8. Ecological Surprises

8.1 Fixing oil spills

In 1988, the *Exxon Valdez* ran aground off the Alaska Coast, discharging 35,000 tons of crude oil. Like previous mega-spills (*Torrey Canyon* – 120,000 tons in 1967 and the *Amoco Cadiz* - 220,000 tons in 1978) the results looked very ugly on TV, especially pictures of oil-soaked birds and distressed seals. The predictable response to public outrage and public

[48] Development Debacle: The World Bank in the Philippines. W. Bello, D. Kinley and E. Elinson. 1982. Institute for Food and Development Policy, San Francisco.
[49] Poverty, basic needs, and employment: a review and assessment. World Bank, confidential first draft. January 1980. Washington, D.C.
[50] The Green Revolution in the Punjab. V. Shiva 1991. The Ecologist 21(2): 57-60.
[51] New Scientist. 20 January 2001.

pressure was to attempt a technological fix to a visibly technological disaster. Subsequent studies of the $2 billion *Exxon Valdez* cleanup and earlier efforts, however, have shown that these often added to the ecological disruptions. For the *Valdez,* there was a heavy reliance on hot-water sprayed through high velocity pumps. Later reports suggested that the high-pressure cleanup had numerous unintended impacts: it destroyed mussel and rockweed populations; killed many organisms that had survived the oil; drove sediment and oil into a sub-tidal area rich in marine life that had largely escaped the initial oil; damaged eelgrass communities; killed clams and crustaceans in inter-tidal and sub-tidal zones; and disrupted the natural sediments of beaches which in turn smothered clams and worms.[52]

The conclusion was that a less costly strategy would have been more effective and less risky to the environment. These spills underscored the complexity of natural systems and the need for creative, flexible and cautious approaches to them.

8.2 Acid rain

"*The solution to pollution is dilution.*"

Over 100 years ago British chemist Robert Angus Smith used the term "acid rain" when he realised that smoke and fumes from human activities could make rainwater more acidic. It was another 50 years before the environmental consequences of this fact started to be recognised. Through to the 1970s the common approach to getting rid of air pollutants from industries (such as ore smelting) and sulphur fumes from coal-burning electric power plants was to build very high smoke stacks and leave it for the wind to disperse. The idea was to dilute the outputs over a large area. (Other efforts were made to control pollution by neutralising acidic gases and removing particulate matter from exhaust gases. Such technologies were not 100% efficient at doing so.)

Around the 1950s, increased levels of acidity were discovered in lakes throughout Scandinavia and eastern Canada. At first, this was merely regarded as interesting. Then over a period of years biologists noted declines in fish populations, reproductive failure in frogs and losses in insect populations of stream and lake-dwelling species. In some particularly acidic lakes all the fish and insects disappeared following the death of the plankton species that supported the rest of the aquatic food chain. Forests in these regions, and in Eastern Europe, also started showing signs of stress as pine needles yellowed and trees started dying. By the late 1970s, thousands of lakes in Canada and Scandinavia were 'biologically dead'.

It was the accumulation of research results, field and atmospheric monitoring and lab experiments over decades that finally led to an understanding of the complex cause and effects of acid rain. Coal burning and vehicle exhausts release oxides of sulphur and nitrogen into the atmosphere where they react with water vapour to form weak solutions of nitric and sulphuric acid. Thousands of kilometres from their point of release, these products return to earth as dry particles or acid rain. Hence half the acid rain that falls in Canada originates from sources in the United States and British acid rain products are deposited in Scandinavian countries.

[52] Soiled shores. M.Holloway. October 1991. Scientific American.

Soils, surface waters and forests can all be damaged by acid rain. The actual interactions between aquatic organisms and changes in water chemistry are extremely complex. For example, large runoffs of melting (acid) snow in spring can briefly, but significantly raise stream acidity levels and kill the eggs of fish and amphibians. Acid rain dissolves nutrients out of leaves and out of the soil while also 'activating' aluminium, lead, cadmium and mercury in the soil. Such toxic metals reduce the trees' ability to absorb essential nutrients. These combined stresses have caused widespread forest mortality in heavily polluted parts of Eastern Europe.

Reducing total emissions requires effort on several fronts. First, the development of emission control technologies that remove most of the acidic gases before they are released into the atmosphere. Second, providing alternatives to high sulphur content fuels and third, the use of energy technologies that do not emit oxides of sulphur or nitrogen.[53] There is concern that these options will not be part of the major industrialization in East Asia and, as a consequence, rising acid rain levels could have severe ecological and agricultural impacts in countries such as China and South Korea. This time, however, the cause and effect relationships are well understood in advance of the potential impacts.

8.3 Fire ant fiasco

The fire ant fiasco combines the story of an invasive species with the misplaced efforts of US agricultural interests to demonstrate the power of pesticides. It provides several lessons: the dangers of using pesticides whose impacts are not known; the risks of large-scale 'eradication' campaigns; the complexity of ecosystem responses; and the nasty consequences of selection pressures on target species.

The fire ant (*Solenopsis invicta*), named after its fiery sting, first arrived in Alabama from the Paraguay River floodplain after the First World War. It slowly spread into most of the southern states over the next 40 years and "seems to have attracted little attention."[54] It was certainly a nuisance species, but there was little evidence of economic damage. Then in 1957, the US Department of Agriculture (USDA) started a major publicity campaign followed by an 'eradication' campaign to cover 20 million acres across nine southern states. An agricultural historian believes this was an effort by the Agricultural Research Service of the USDA and the land grant universities to show that the future lay with organochlorine pesticides, like DDT, not with biological control.

The spraying programme used dieldrin and heptachlor, both relatively new organochlorines, for which there was little experience of field use. No one knew what their effects would be on wildlife, mammals and fish when applied on a massive scale. By then it was known that one pound of DDT per acre killed some birds and many fish. Dieldrin was twenty times more toxic than DDT and heptachlor was also more toxic than DDT. The application rates of dieldrin and heptachlor were equivalent to about 80-100

---

[53] These include sulphur dioxide, sulphur trioxide, nitric oxide, nitrogen dioxide, and nitrous oxide.
[54] Silent Spring. R. Carson. 1962. Penguin Books. Carson gives a full account of the early stages of the fire ant story.

pounds and 20 pounds of DDT to the acre respectively. There had been no preliminary research to determine appropriate dosage rates. Urgent protests by state conservation departments and ecologists were ignored and the spraying started in 1958. In many areas there was a massive loss of wildlife, particularly quail and wild turkeys, while poultry, livestock and pets were also killed. Surviving earthworms in Louisiana were found to have up to 20 parts per million of heptachlor in their tissues 6-8 months after treatment of the area. Woodcocks, which feed heavily on earthworms, suffered sub-lethal poisoning and a marked decline in breeding success.

The recognition that heptachlor quickly reacts to form the more toxic heptachlor epoxide in living tissue or in soil led to its discontinuation in the early 1960s. It was replaced by mirex, which in turn was found to harm wildlife and marine life, and to possibly cause cancer in humans. Meanwhile, the pesticide applications led to an upsurge in insects that attacked sugar cane. Heptachlor, mirex and the other pesticides killed not only fire ants, but their natural insect enemies as well – especially the species that normally eat fire ant queens. This allowed the fast-breeding fire ants to recover swiftly and take over the roles its insect enemies and competitors could no longer defend. Using broad-spectrum insecticides helped fire ants change from constituting 1% to 99% of the resident ant population in only four years.

Not until 1978, 14 years after the death of Rachel Carson in 1964, did the spraying programme stop. It had cost $200 million and left more fire ants behind than ever. By 1990, fire ants occupied 400 million acres in southern and southwestern states. They are now widespread in California and cost tens of millions of dollars annually in stock losses, control measures, and medical costs.

The fire ant fiasco may turn out to have an evolutionary epilogue. In 1972, after fifteen years of the heptachlor and mirex campaigns, multiple-queen colonies were first observed. This behaviour is unknown in the original South American habitat. Normally single-queen colonies compete with one another and attack stray ants from neighbouring colonies. The multiple-queen colonies, linked by tunnels, seem to form an extended fighting organisation capable of wiping out almost all other forms of insect, reptile, bird and rodent life in its path. Pesticide spraying may have promoted the change by inadvertently selecting for genes previously expressed only rarely.[55]

The advances of new colonies into southern California, justifies Carson's earlier dismissal of the programme: "*It is an outstanding example of an ill-conceived, badly executed, and thoroughly detrimental experiment in the mass control of insects…it is incomprehensible that any funds should still be devoted to it.*"[56] It is also another reminder of the risks of overstepping the boundaries of knowledge and applying an untested technology where there were adequate warnings of the potential for negative outcomes.

---

[55] Fire ants play their queens into a threat to biodiversity. C.L. Mann. 1994. Science Vol 263 (no 5153); 1560-61.
[56] Carson, ibid. Page 148.

8.4 Introduced species

Fire ants possibly arrived in the USA as 'hitchhikers' on shipping goods and later became "invasive".[57] This section will briefly cover the complexities and consequences of deliberate introductions of alien species, with a focus on the inherent uncertainties involved and the relevance of the precautionary principle.

Many countries, including New Zealand, have developed their primary production sectors based largely on the use of plants and animals that were deliberately introduced from other countries. Other species were introduced to New Zealand for recreational (deer, thar, chamois) or cultural (many ornamental plants) reasons. A more scientific and management rationale for other introductions has been for biological control purposes using plants or animals, instead of chemicals, to reduce the impacts of pests and weeds. Biological control agents are now usually subjected to rigorous screening to determine what risks they may pose to other non-target species.

Sometimes deliberate introductions have gone disastrously wrong, as with the introduction to New Zealand of the Australian brush-tail possum (to establish a fur industry) or deer species for hunting. Decades after possums were introduced an eminent New Zealand zoologist was asked to comment on the future impacts possums might have on New Zealand native forests. His conclusion was that possums would have little impact and would be easy to control since females usually only had one young per year. Many early attempts at biological control were equally misplaced in their rationale and outcomes. For example:

- Weasels, stoats and ferrets were introduced to New Zealand to control rabbits, but found it easier to prey on the more vulnerable native birds.

- Cane toads were introduced into Queensland to control insects in sugar cane plantations but became an unstoppable menace themselves.

- Attempts in tropical countries to control snail pests by releasing a carnivorous snail from Africa were counter-productive; the African snail also preyed on many indigenous snail species and has made numerous snail species extinct as a result, including several in Pacific island countries.

While the science of biological control has become more sophisticated since these errors were made, there is one important lesson to be learned from the global history of deliberate and accidental introductions. Namely, there will always be inherent uncertainties about the consequences of biological introductions. For example:

- Chamois in their native Austria occupy small home ranges and travel only short distances between summer and winter pastures. In New Zealand they behave very differently, some move regularly across the Main Divide, range over hundreds of square kilometres and may live in

[57] Invasive species – species that establish beyond their natural range through human intervention (deliberate or accidental) and have negative impacts on local biodiversity.

forest. This has implications for management that were not predictable from chamois behaviour in Austria.

- A flatworm, native to New Zealand, is currently causing significant economic damage to British agriculture by destroying native earthworms. In parts of Scotland earthworms have been reduced to ‘below detectable levels’ and moles numbers have fallen as a consequence. The same flatworm is not an agricultural problem in New Zealand and its major impacts in Britain could not have been predicted.

The reason such uncertainties exist is because ecological systems are very complex and dynamic, responses are not linear and vary over time and space, and are further influenced by human factors. For example, climate change will influence the impact of invasive species. Rising temperatures will allow disease-carrying mosquitoes to expand their ranges and may increase their number of life-cycles per summer. Higher temperatures may enable innocuous introduced plants to become invasive, due to subtle changes in their heat requirements for growth and seeding. Stressed ecosystems respond differently to those that are unstressed, making it difficult to predict which species will rise or fall as a consequence.

9. Key Lessons

“*Nothing will be more important to human well-being and survival than the wisdom to appreciate that however great our knowledge, our ignorance is also vast. In this ignorance we have taken huge risks and inadvertently gambled with survival. Now that we know better, we must have the courage to be cautious for the stakes are very high*.”

Our Stolen Future, 1996[58]

“*This brilliant work heralds the new age of nanotechnology, which will give us thorough and inexpensive control of the structure of matter.*”

Publisher’s promotion for ‘Engines of Creation’ by K. Eric Drexler 2000

This section will summarise lessons from the paper that are relevant to the current debate about genetic modification.

9.1 Technological complexity and uncertainty

Did an iceberg sink the Titanic or unfounded technological optimism, over-confidence and pride? The presence of sea-ice was known, its lethal impact already demonstrated numerous times. For its time, the Titanic was a complex structure, but claims about its ‘unsinkability’ were not based on experience or testing in practice. Certainly the high loss of life was due to a failure to plan for the unexpected. It demonstrated the sometimes catastrophic shortcomings of the “fail-safe” approach – build something that will never fail – over the more precautionary “safe-failure” approach – namely, have enough lifeboats and well-drilled crew, just in case of major impacts (with icebergs).

[58] Our Stolen Future, ibid. Page 249.

Modern aircraft designers appreciate the risks that accompany technological complexity and therefore build in 'surplus' systems to reduce the risks to aircraft safety. Like civil engineers that learn about effective design from bridge collapses, aviation engineers add to their knowledge base from air crashes. The result is safer systems and a robust risk assessment approach capable of reasonably reliable predictions. Reliable predictions come from the fact that the objects were built by people, are therefore well characterised, and only affected by a limited number of factors.

The lessons from nuclear power plants are more complicated. The technology itself is so complex that calculating the accident probabilities becomes more problematic and less amenable to formal risk analysis. Calculations of plant safety also assume standards of operational vigilance and maintenance regimes for "repeated rituals" that are difficult to maintain, given the occasional fallibility of humans and the social influences on their working effectiveness (as in the former Soviet Union). In addition, the nuclear industry assumed, wrongly, that the problem of safely storing radioactive wastes was just a technical question. After 40 years of trying to resolve this issue, there is no consensus beyond the realisation that finding a solution involves profound social, political and ethical issues, in addition to those of geology and technology.

9.2 Biological complexity and unpredictable surprises

When we switch from examples of uncertainty and risk in the behaviour of built objects to examples involving biological systems we encounter qualitatively different levels of complexity as well as unpredictable, sometimes nasty, surprises. CFCs that are chemically stable at ground level turn out to deplete ozone resulting in dangerous levels of UV radiation and increased risk of skin cancer, especially in the Southern Hemisphere; airborne asbestos fibres can lead to deadly cancers; miracle pesticides have deleterious effects on species and ecosystems, and can disrupt human development by mimicking hormone function; acidic air pollutants kill lake ecosystems and damage forests hundreds of kilometres distant from their source; and in many counties invasive species cause economic and environmental damage in ways that were unpredictable in their native habitat.

Many of these cautionary tales, as well as the medical ones, describe biological surprises with effects that are distant in time as well as space. Both asbestos particles and prions produce fatal diseases sometimes two or more decades after the exposure or transfer actually occurs. Hormone mimics jump a generation to affect the developing foetus, not its unsuspecting and healthy mother. The upper atmosphere is unexpectedly effective at transporting (radioactive) particles and chemicals thousands of kilometres from their starting points. Nor are these processes that can easily be slowed or reversed, as shown by the research on climate change and the increase in pesticide and antibiotic resistance.

The approach to risk assessment that usually works for built objects therefore runs into serious problems when applied to biological systems. It was usefully adapted for calculating acceptable discharge levels for pollutants of biological origin (eg. oil and animal wastes) and other naturally biodegradable pollutants. In these cases it is possible to estimate how much a system can absorb (eg. a river or estuary) and therefore calculate acceptable levels of discharges. The presumptions of assimilative capacity and acceptable discharges do not work for persistent chemicals that accumulate over decades in the environment and are concentrated up the food chain. These substances are fundamentally different from degradable pollutants as the examples of organochlorines pesticides and synthetic hormone disruptors demonstrate. Complexity, lack of data and ignorance of impacts all exacerbate the difficulties of making useful predictions. This will be taken up further in Section 9.5 where the issue of how we should respond, when our understanding of biological systems is incomplete, will be explored.

9.3 Complex science for complex problems

In some of the above cases it has taken many decades and major advances in scientific understanding and measuring techniques before the underlying relationships were elucidated. Biological impacts of persistent toxic chemicals and global-level processes have taken much longer to understand than lessons from technological changes. Nor should we presume that any remaining uncertainties are fully amenable to scientific enquiry, despite our better understandings of complex systems.

It is important to acknowledge the historical success of scientific theory and practice in solving "problems of simplicity" and problems of "disorganised complexity".[59] Changes in both theory and practice may be required, however, to deal with more complex and "messy" situations characterised by problems of "organised complexity".

The consequences of complex systems and their associated "irreducable uncertainty" led Gallopin *et al* to argue for a new approach to science.[60] While retaining scientific rigor, they propose that the initial definition of issues or problems should include a wider range of factors, including ones involving non-scientific analysis. "*It is better to get an approximate answer for the whole problem/issue, than a precise answer for an isolated component.*"

This argument applies particularly to ecological and environmental issues, where systems and their inter-relationships are complex or not yet well understood. In these circumstances it can be difficult or impossible to determine direct cause and effect, and there can be serious consequences if the absence of proof of danger is mistaken for proof of the absence of danger. The significant time lags that occur before effects appear in complex systems can give a false sense of safety and increase the chances for disasters. We need look no further than the impact of invasive species (Section 8.4) to appreciate the ecological and economic costs of making this error. The consequences of the potential for genetically modified organisms to act in unpredictable and uncontrollable ways in the wild has strong parallels with the lessons that can be drawn from invasive species.

---

[59] Science and complexity. W. Weaver. 1948. American Sci. 36: 536-544.

[60] Science for the 21st century: from social contract to the scientific core. G.C. Gallopin et al. International Journal of Social Science Vol 168 (in press).

The model for scientific research into complex systems that Gallopin *et al* propose has the following features. Such research would:

- Include policy relevant indicators at the beginning of the problem definition.
- Involve policy makers and stakeholders in the initial problem characterisation. (As recommended in the Dam Commission report – see 4.1).
- Clearly distinguish between the knowledge base (including scientific uncertainties) and the political decisions (incorporating social values).
- Consider the possible behaviour of the whole system as broadly as possible. Therefore prepare for novelty, structural change and surprise.
- Value the information generated by the responses of the system to policies and human actions.

International efforts to understand global change processes, including the work of the Intergovernmental Panel on Climate Change, reflect these new requirements in operation. The Panel accumulates relevant knowledge, which is then interpreted by a community of scientists from several disciplines. These interpretations are then disseminated to advance more science and to inform and assist the development of policy.

The many mistakes made by scientists and government officials in the case of BSE (Section 7.3) demonstrated the consequences of not incorporating features of this model into research on complex systems.

9.4 An Ecological Paradigm and the need for precaution

A leading ecologist, C.S. Holling, has characterised ecological science as capable of bridging gaps between two very different scientific ways of seeing the world.[61] One way is well represented by advances in molecular biology and genetic engineering. It is an analytical stream of biology that is essentially experimental, a science of parts, reductionist, and disciplinary in character. The second stream is integrative, broad and explorative, characterised by evolutionary biology. Its premise is that "*knowledge of the system we deal with is always incomplete. Surprise is inevitable.*"

Holling goes on to say: "*In principle, therefore, there is an inherent unknowability, as well as unpredictability, concerning ecosystems and the societies with which they are linked. There is, therefore, an inherent unknowability and unpredictability to sustaining the foundations for functioning systems of people and nature.…*

The bridge between the two comes with the realisation that neither is complete in itself: "*Both the science of parts and the science of the integration of parts are essential for understanding and action.*" Each has

[61] Two cultures of ecology. C.S. Holling. 1998. Conservation Ecology 2(2):4. [online] Available from: www.consecol.org/vol2/iss2/art4

the responsibility to understand the other. "*Otherwise the science of parts can fall into the trap of providing precise answers to the wrong question and the science of the integration of parts into providing useless answers to the right question*."

From this view of ecology we can identify an Ecological Paradigm. This paradigm recognises the limits of science and the reality of incomplete knowledge. It is derived from ecology, not from engineering, and recognises the complexity of ecosystems and organisms. It is integrative and "*interprets evidence in a precautionary framework that seeks to minimise false judgements that no hazard exists when in fact one does.*" [62]

9.5 Managing risk and maintaining trust

"*The Titanic sank in a sea that was 99% free of icebergs*."
Dr J. Carman, Flinders University, South Australia, 2001

Over the past 50 or more years, the science of risk assessment has developed methods to estimate the levels of risk that are likely to follow from a variety of human actions, such as building bridges, releasing chemicals into the environment or using new drugs for human or animal purposes. Based on risk assessments, cost-benefit calculations can be made, policies established, and regulations set to govern a range of industrial activities. Risk assessment is an integral part of risk management; it provides the scientific basis ('the facts') to assist decision-making, such as determining acceptable levels for x-ray doses or factory discharges. What is an 'acceptable level' may change as understanding improves, both among the experts and the public. Investment in risk management reflects a wish to reduce risks, at least to manageable extent, and therefore to increase safety, for individuals and society.

As this paper has shown, there are new forms of technological risks, particularly to biological systems, which are hard to perceive directly, both literally and conceptually. They may transcend generations and we are groping with the realisation that an appropriate compensatory mechanism may not exist. "*Developing solutions to these new forms of risks is limited by a heavy reliance upon the very scientific and technological systems that generated the problems in the first place*."[63] This realisation was very evident in Britain following the BSE crisis, which in turn sensitised the British public to perceived risks of food safety from GM crops. "*The [resulting] protest is essentially about re-democratising the debate so that values other than purely scientific and technological ones can be injected into the deliberating process*."[64]

Behind this public protest are two fundamental issues. First, a challenge to the inherent assumption in the science of risk assessment, namely, that it is capable of dealing with uncertainties in a comprehensive way. The outcome of such assessments is a scientific quantification of risk, which can then be considered for its acceptability (by the public or decision-makers). But the

---

[62] Pandora's Poison. Chlorine, Health, and a new Environmental Strategy. J. Thornton. 2000. MIT Press, Cambridge, Massachusetts.
[63] Environmental risk management. S.Gerrard, 2000. In Environmental Science for Environmental Management. Ibid. Pages 435-468.
[64] Gerrard, ibid. Page 435.

uncertainties that can be recognised scientifically are only the *known* uncertainties, writes Brian Wynne: *"This totally and silently excludes from consideration the unknowns, which result in unanticipated consequences…"*[65]

The *"pervasive importance of the unknowns"* that Wynne empahsises, and which are an integral part of Holling's model of the reality of human-nature systems, (Section 9.4) are not universally recognised or accepted within science. Wynne gives as an example of the attitude that recognises only known uncertainties, the following response of Bob May, recently retired UK Government Chief Scientist, to concerns over unknowns with respect to GMOs. May wrote that: *"Lessons have been learnt [from BSE]…We must test. No-one was looking for untoward effects in cattle. In the case of GM foods we are testing for unexpected and unwanted effects on human health and the environment."*[66]

This presumes that we know what to test *for*. May's stance completely ignores the fact that the very existence of prions was not known when he says they could and should have been testing for them. The role and behaviour of prions is still a mystery. Testing for as much as possible is clearly important. In doing so we must recognise, however, that testing can only deal with the scientifically tractable problem of known uncertainties. The more serious predicament of scientific ignorance and unpredictability or focusing attention in the wrong areas remains and will always remain.

The second challenge behind the public protest in Britain, as elsewhere, is against the down-grading of ethical concerns and the presumption by scientific experts that the intellectual power of scientific risk knowledge has sovereignty over the larger issue of consequences. The BSE inquiry revealed how science had become *part* of the policy culture, rather than its key intellectual resource. In such a culture, ethical dimensions behind public concerns are accepted, assuming they are of a 'touchy-feely' kind and essentially without substantive content.[67] This attitude leads to the effective dismissal of public concerns and retains the dominant role for science in policy formulation and decision-making.

This means that public concerns about the purposes and the driving forces behind innovation research are misunderstood as exaggerated and irrational concerns about 'too much' uncertainty or risk. Instead, Wynne argues, the public is expressing a mature appreciation of the need to ask: why do we want to unleash those possible unknowns? Is there a good reason? The public asks these questions recognising there is more uncertainty about the undertaking than is admitted by science.

There is an important consequence to recognising the inherent unknowability and unpredictability about complex systems involving people and nature. It is that information and decisions are therefore vulnerable to being

---

[65] Expert discourses of risk and ethics in genetically manipulated organisms: the weaving of public alienation. B. Wynne. (In press.) Politeia.
[66] Scientific advice to Government, paper from UK Office of Science and Technology 2000. Quoted in Wynne, ibid.
[67] Wynne, ibid.

manipulated by powerful interests.[68] Examples of powerful interests manipulating uncertainty are given in this paper.

This leads to a brief mention of the issue of trust in science and scientists. Increasingly, scientists are perceived as being more responsive to the concerns of the private sector and their funding sources than to the public good. Statements in favour of GM by scientists from companies that produce and sell GM products are increasingly viewed with scepticism. The public remembers assurances from scientists within the military, agri-business sector and pharmaceutical companies over the safety of atmospheric fall-out, pesticides and thalidomide respectively. It also recalls the role played by other scientists in more independent positions in exposing these hazards.

9.6 Lessons for biotechnology in New Zealand

New Zealand is at a critical point with respect to its ongoing relationship to biotechnology, as demonstrated by the establishment in 2000 of the Royal Commission on Genetic Modification. What might be the actual or potential effects on the environment, including people and communities, of utilizing GM technology and products in New Zealand? These examples from the history of science and technology point to a number of lessons that can usefully inform this dialogue.

- The immature phase of new technologies or scientific applications are often marked by surprises and failures, despite initial expressions of optimism.
- In the case of engineering technologies the maturation phase leads to fewer unknowns, safer operations, better understanding of risk factors and often more circumscribed operational practices. Occasionally, the development of extremely complex technologies is curtailed or dropped because of excessive costs or unresolved problems.
- Medical advances often follow the same pattern of: initial optimism, lack of understanding of complex effects, and more judicious use as knowledge of the human responses improves (e.g. use of X-rays, antibiotics). Given the complexity of organisms, however, surprises (e.g. the existence of prions) will continue to emerge.
- Some new materials and chemicals have had delayed negative impacts on human health (e.g. asbestos, persistent organic chemicals) and the environment (e.g. CFCs) that could not have been foreseen at the time they were introduced. These impacts have been global, systemic and complex, both in time and space. These are qualitatively different outcomes from the impacts of engineering technologies.
- Other initiatives that sought to directly change environmental conditions (e.g. big dams) or enhance biological production systems (e.g. pesticides) have also resulted in adverse unintended and unexpected effects after initial positive outcomes. These have exposed a lack of understanding of underlying cause-and-effect relationships.
- Many severe and unintended environmental outcomes only emerged decades after the initial use of the technology and then sometimes in a different place. Initial success should not be taken as evidence of overall net benefit, especially when operating at ecosystem levels.

---

[68] Holling, ibid.

- Although scientific and ecological understanding is always increasing, knowledge of organisms, ecosystems and people-nature relationships will always be incomplete because of their dynamic nature, organisational complexity and ongoing evolutionary changes.
- It is a sobering reminder that a number of medical and engineering advances have been dependent on painful lessons learned as a consequence of human tragedy. Sometimes individuals were affected (e.g. thalidomide), but the power of science has the potential for harm to be more pervasive and global (e.g. lead additives and persistent organic pollutants).
- Accepting there is an 'unknowability' element in scientific uncertainty poses a fundamental challenge to the science of risk assessment. Solutions to new forms of risk cannot rely exclusively on scientific and technological systems. Consequently, there is a need to recognise the limits of science, the importance of applying the precautionary principle, and the relevance of ethical concerns to policy formulation and decision-making.
- There are a number of cases where harm has continued to be done after negative consequences have been demonstrated, because of the actions and influence of commercial or sectoral self-interests. This has reduced public trust in the organisations involved and in decision-makers, as well as raising doubts about the independence of scientists linked to commercial or funding interests.
- In recognition that complex problems, such as global change, require a correspondingly sophisticated approach to scientific research, new models are being developed for linking the findings of scientific research to the policy process and to community concerns. These models are part of more dynamic and participatory approaches to decision-making. Such models require equal attention to scientific rigour, to transparency of process and to justifying public trust as we face the challenges of new technologies and their potential applications in an already compromised world.

Let us learn from history. All these "lessons" imply that the progress of genetic sciences and their applications be punctuated by unpleasant surprises, disasters and consequential remedial action. But these "lessons" also indicate we could reduce the surprise elements if we, as a society, were prepared to acknowledge the optimism that characterises new sciences and technologies and take a more precautionary approach. This is an imperative when the science involves the capacity to create new life forms – something fundamentally different from any of humanity's previous endeavours.