

CHAPTER 1

A CASE OF MISDIRECTION

In the 1980s, nanotechnology offered the potential fulfillment of a dream for anyone concerned with the future of the planet. It was becoming apparent that we would one day need to reduce the quantity of materials and energy used in making all our machines. Today, for example, manufacturing a PC consumes 240 kilograms of fossil energy, 22 chemical products and 1500 liters of water. Producing a single USB key entails 250 liters of water and numerous chemical pollutants.¹

Our hope was that nanotechnology, then in its infancy, would liberate industry from the mass use of materials, and usher in a new era of sustainable development. That was the aspiration I shared with a number of other researchers. At the time, I drew up my own state-of-the-planet assessment, which still reminds me of that youthful aspiration. I used to amuse myself by looking for new, environmentally safe technologies in different industrial sectors. One of these was the research by Kevin Ulmer, research director at Genex in California, on the possibility of manufacturing ultraminiaturized electronic circuits using proteins produced by genetically programmed bacteria. His ideas were only one step away from the edible computer! The work of the American chemist Ari Aviram, at IBM's T. J. Watson research labs near New York, was also high up on my list. His aim was to design a single molecule that would act as an electronic component. He was working on an electrical switch consisting of a current-blocking molecule, or a molecular electrical rectifier — in other words, a molecule that would only allow current to flow in one direction.

¹Ruediger Kuehr and Eric Williams, *Computers and the Environment: Understanding and Managing their Impacts* (report for UNESCO) (Kluwer, Dordrecht, 2003).

In the same vein, Forrest Carter, a US chemist working at the NRL (Naval Research Laboratory), imagined making not just single components, but whole electronic circuits, from just a few molecules. These projects raised the prospect that microelectronics might become “nanoelectronics,” mitigating the environmental impact of the electronics industry.

I was not the only one looking for more environmentally friendly alternative technologies. In his doctoral thesis, Eric Drexler, a young engineer at MIT (Massachusetts Institute of Technology) in Boston, had imagined devices other than molecular components and electronic circuits. In his 1986 book *Engines of Creation*,² he describes a very remote future when molecular machines would recycle waste and produce pure water and energy. These machines, stripped to their essentials, i.e. to a few molecules, would take our civilization into the era of molecular technology.

However, these fine projects were absorbed by nanotechnologies in the broad sense — those based on the classic techniques of micromanufacture — and finally came to nothing. Today, people do not associate nanotechnologies with hopes for less resource-hungry industries, but with anxieties of different kinds: Might they be poisonous? Might they escape our control? We will return to these questions in Chapter 6. How did we get to this point? What caused the shift from all that environmental promise to this sense of mistrust? An analysis of the emergence of what has come to be called the “nano bubble” casts light on this change in the values associated with nanotechnology.

Political Hijacking

It was a time of promise, the start of the nanotechnology adventure, the 1980s. A few researchers, myself included, were working on molecules capable of performing electronic functions and were moving into the field of molecular electronics opened up by Ari Aviram and Mark Ratner. Others were exploring a fantastic new instrument, the scanning tunneling microscope, invented in 1981 by G. Binnig and H. Rohrer (Nobel Laureates in 1986), which was capable of “seeing” atoms and molecules and, above all, of manipulating them individually, as was invented by D. Eigler

²*Engines of Creation: The Coming Era of Nanotechnology* (Anchor, New York, 1986).

in 1989. They launched the first experiments to be conducted directly on a single molecule. However, these experiments made little impact and the scientific fraternity — especially in Europe — was often skeptical as to the potential of the STM. Nanotechnology was still a small field. By 1995, there were only five teams capable of atomic scale manipulation: three in the USA, one in Europe and one in Japan. It was my good fortune, having worked with Aviram, to be a member of one of these pioneering teams, under Jim Gimzewski at the IBM laboratory in Zürich, which was attempting to manipulate ever-larger molecules with an STM. Few though we were, we made progress and discovered, sometimes by chance, some curious phenomena, which will be described in Chapters 3 and 4. Research should have continued along these lines, but that is not what happened.

Instead of that, events in the mid-1990s took a different turn, driven not by scientific research, but by politics. It all began in the USA, where pressure groups prevailed upon Congress and the Clinton administration to launch a major program called the National Nanotechnology Initiative (NNI). It is worth dissecting the origins of this program to understand how and why nanotechnology diverged from its original calling (the manipulation of atoms) and its original purpose (ecotechnology) to follow a quite different path in the NNI, to become “nanotechnologies” and to be swallowed up by the global technosphere, first in the USA and then worldwide.

In June 1992, ecotechnology was all the rage. Tennessee senator Albert Gore came back from the second Earth Summit in Rio de Janeiro with his environmental instincts so fired up that he organized a Senate hearing for the top US specialists on the topic of “new technologies for sustainable development.” One of the people heard was Eric Drexler, whose book had aroused a surge of interest. When it was published in 1986, the manipulation of atoms to produce nanocomputers and other nanomachines was no more than a very hypothetical possibility, disputed by many scientists. In 1989, however, the world discovered that the STM could be used to move atoms around. Suddenly, Drexler and his book had gained new credibility. On June 26, 1992, therefore, he was invited to address the committee of American senators assembled by Al Gore. His talk was remarkably unsensational. He explained that building a machine molecule by molecule could be a cleaner and more efficient process than was possible with existing technologies. To lend the project scientific credibility, he cleverly cited the name

of Richard Feynman, winner of the Nobel Prize for Physics, unearthing a 1959 speech in which the illustrious physicist had mentioned nanometric scale manufacture. And, finally, he played the hole cards of national pride and competitive spirit, pointing out, quite correctly, that the Japanese were investing heavily in research on the manipulation of atoms.

According to the minutes of the hearing, Al Gore was won over to the project described by Drexler in the Q&A session. Although he had started out simply interested in miniaturization, within a few minutes he signed up for this nanotechnology, with its potential to assemble “molecule machines” directly from atoms and molecules. A technological development pressure group was then created, with Drexler playing the role of a modern Jules Verne, a master of technological prediction, and founding his California-based Foresight Institute.

During this time, as Drexler had mentioned, the Japanese government had launched a research program on the manipulation of atoms. Its goal was to support the future of the country’s microelectronics sector and not to fall behind the Americans! Results were not slow in coming. At Japan’s Riken public research laboratory, a researcher called Masakura Aono was working on the construction of atomic scale circuits. He succeeded in developing atom-by-atom engraving on a silicon surface using an STM. The Japanese and the Americans were now neck and neck.

Back to politics. Bill Clinton, elected president in 1992, put his Vice President, Al Gore, in charge of new technologies. The USA was facing a number of challenges. The end of the Cold War had changed US research priorities, shifting the focus to international competitiveness. The goal was no longer simply to support military research, but to strengthen R&D programs on nonmilitary consumer goods. The excellent health of the Japanese and Korean electronics industries was giving US industrial bosses sleepless nights. To protect American research, it was essential to re-resource the universities, which were working with largely obsolete equipment. Gore was essentially given the task of reorganizing US research, a job that involved money, lots of money. Drawing inspiration from the great scientific program headed by President Roosevelt at the end of World War II, he delivered his conclusions in August 1994, in a report entitled “*Science in the National Interest.*”

Does the report promote the ecotechnology project that had so excited Gore two years earlier? Alas, it contains little if anything on sustainable

development The Vice President's initial interest in the environment had evaporated along the way.³ Instead of supporting research on the manipulation of atoms and molecules, which might foster a more environmentally friendly industry in the future, the report proclaims that nanotechnologies are strategic to America's current industrial development. Nanotechnologies have suddenly become crucial, not to the sustainable development of the planet, but to the immediate future of the national microelectronics, chemicals and pharmaceuticals industries. So what had happened in those few years?

Given the scale of the challenge of reorganizing US research — and the money that went with it — an industrial lobby had stepped up to influence the contents of the report. The “pro-sustainable-development” pressure group that had gravitated toward Al Gore, with Eric Drexler as a key player, had to give way to this new rival. In the space of two years, Drexler's star had waned. He was under attack from many scientists critical — not without reason — of the lack of a scientific basis in his work. Some American newspapers even began to liken him to the guru of a cult, his Foresight Institute. Gradually, he lost influence and credibility.

The industrial lobby found its champion in the person of Mihail Roco. A former professor of mechanical engineering, Roco was appointed in 1990 to head the Engineering division of the US National Science Foundation (NSF). In 1995, he launched a research program on the use of nanoparticles in materials. For this program, he requested and got the green light from the Director of the NSF, Neal Lane, Professor at Rice University in Texas, who in 1998 would become scientific adviser to President Bill Clinton. Roco was a reasonable and tenacious academic who for five years had fought hard to build American nanotechnology. For him, Eric Drexler's ideas of molecular factories were fantasies, and nanotechnology — in the sense of molecular technology — had little future. He was one of those who were convinced that the top-down technological approach of miniaturization was the only valid option. He considered the term “nanotechnologies” to encompass all the technologies of miniaturization that operated within spitting distance of the nanometric scale.

³His interest in sustainable development was to re-emerge in 2006, with the film *An Inconvenient Truth*, and would win him the Nobel Prize for Peace in 2007.

In early 1997, Tom Kalil, President Clinton's economic adviser, contacted Roco. He had read Al Gore's report and wanted to assess the possible economic implications of the nanotechnologies. With the help of Kalil, Roco then set up a working group which, after two years, culminated in the creation of the NNI. They had to convince a dozen agencies responsible for funding nanotechnologies in the USA, draft a plan that could command a consensus and above all deal with opposition from senators who wanted to see funding go to other programs.

There was reluctance in some quarters about the idea of raiding the nation's coffers for these nanotechnologies, however strategic they were supposed to be. To persuade these reluctant senators and dangle the carrot of a molecular technology radically different from anything that had come before, Neal Lane turned to Drexler's book. Roco, however, continued to make sure that the NNI would remain untainted by Drexler's molecular machines. The industrial lobby did its job well: following a final meeting attended by Roco, Lane and Kalil, the NNI was launched on March 11, 1999.

Its initial budget of US\$300 million for the year 2000 was a matter of concern to certain senators. With so little money, they feared, US scientific discoveries in nanotechnology could be exploited by Japan and Europe, which might develop new technologies faster than the USA. Competition was intense: no way were they going to be beaten to the draw! In the end, the NNI's budget grew over the years to US\$970 million in 2005. The NNI has survived the political changes in Washington. The 2008 budget approved by President George W. Bush was for US\$1.447 billion. There is no question that removing sustainable development from the NNI agenda was a boon for the survival of the program, given President Bush's attitude to that concept

The Temporary End of Sustainable Industrial Development

On June 22, 1999, a short time after the launch of the NNI, the US House of Representatives organized a new hearing on the NNI's finances. One of the key speakers was Richard Smalley, Professor of Chemistry at Rice University in Texas. Wrapped in the prestige of the Nobel Prize for Chemistry,

which he had received in 1996 for the discovery of fullerenes, he was to play such an important role that a third pressure group formed around him. To defend the NNI cause, this Nobel chemist transformed himself into a Nobel nanotechnologist and became the spokesman for a section of the chemistry fraternity. He was smart. In all his appearances before the House of Representatives, between June 1999 and April 2002, he was careful to choose big problems that would strike a chord with the public, such as cancer or energy resources, and to link them with nanomaterials, and hence with nanotechnologies. Exploiting his Nobel prestige, he continued the trend begun by Mihail Roco, of passing a large proportion of materials science off as nanotechnology. Through this approach, he managed to make sure that anybody in the USA doing research in chemistry and materials science got a share of nanotechnology funding.

So, in the end, via a succession of hearings, committees and programs, the NNI's scientific base lost touch with Al Gore's shiny original project for sustainable development. The NNI now covers all of materials science without distinction — from microelectronics to new fuels to biotechnology. It has redefined nanotechnologies so broadly that they now span a wide range of very different techniques and domains. With Eric Drexler out of the picture, Richard Smalley published a series of press articles in 2003 asking him to put an end to his molecular fantasies.

The Planet Goes Nano

On January 21, 2000, President Bill Clinton officially announced the creation of the NNI program at the California University of Technology. A highly symbolic location. Here it was, in 1959, that Richard Feynman had given the speech cited by Eric Drexler in his appearance before the Senate committee chaired by Al Gore. Later, this speech would come to be considered — quite erroneously — as the starting point of nanotechnology. With this political hijacking of Feynman's scientific prestige, the wheel had come full circle.

The NNI's scientific rankings were now headed by the big guns of microelectronics, materials science and biotechnology (rechristened nanobiotechnology for the occasion). Atomic manipulation, molecular electronics and the first prototype molecule machines were relegated to the bottom of the pile.

No country would resist this US definition of nanotechnology. The NNI was the symbol of America's resurgence, and alarm bells were ringing on every continent: "What if the Americans pull off another 'first man on the Moon' coup, but this time planting the flag of technology in the infinitely small?" The European Commission in Brussels and every nation in Europe began scrabbling through their archives on the off chance that there might have been a few projects in the 1990s with a hint of "nanotechnology" as defined by the NNI, just as a face-saving move. Of course, they found such projects in materials and microelectronics, in the race to miniaturize electronic chips. Europe's honor was saved. This would be the new focus of research.

The street-smart operators of research in Europe — and many other parts of the world — grasped the opportunity to get funding for their activities. They jumped aboard the NNI bandwagon, without asking themselves what nanotechnologies really were — what was to be gained? If a European microelectronics or microtechnology lab was getting antsy about future funding, all it had to do was call itself the "European Nanotechnology Centre" to resolve the problem. If a chemistry lab in Germany, Switzerland or France was on the slide, the prefix "nano" would quickly put it back in the frame. If a materials science laboratory needed new hardware, it could raise cash by submitting a "nano-research" project.

In France, a group of experts brought together by the French Observatory for Advanced Technologies (OFTA) worked between 1999 and 2002 to redefine nanotechnology, looking for a definition of the nanotechnology project without reference to the microelectronics and materials science lobbies. But it was already too late. The effect was the same as in the USA. A whole scientific community came into being (if you want funding, there is strength in numbers), calling itself "nano" and effectively defining a new scientific field. A strange way of establishing definitions! Successive French nanotechnology programs were modeled on the big American themes: "miniaturization" for the microelectronics industry, "nanomaterials" for the chemistry fraternity, and a new "biotech" sector. The same process has taken place all over the world.

The European Commission went down the same track with the launch of its big NMP (Nanotechnologies, Materials and Processes) program in 2002. This program covers the whole field of materials, and has nothing whatever

to say about the manipulation of atoms and molecules. However, it does mention sustainable development and recognizes the possibility that nanotechnology could one day become an ecotechnology. Since the early 1990s, microelectronics has also had its own big program, called IST (Information Society Technologies). The main focus is on the “miniaturization” trend in the electronics industry, but it pays lip service to long-term research, some of it reflecting the “monumentalization” approach that will be explored later in this book. At the end of 2006, IST was replaced by a new, ICT (Information and Communication Technologies) program, which for the first time in a European Commission program mentions atom manipulation and the use of individual molecules to perform an electronic function.

What can we learn from this story? That economic competition and vested interests are often more powerful than scientific aspirations, which often rest on somewhat utopian foundations. The scientific establishments of the different countries arrived at a highly elastic definition of nanotechnology in order to protect and justify this political hijacking. “Nanotechnologies are the design, characterization, production and application of structures, devices and systems by controlling shape and size at nanometer scale,” states the UK’s Royal Society and Royal Academy of Engineering. According to other definitions, nanotechnologies begin when new physical phenomena appear in samples measuring less than 100 nanometers in at least one direction.

That is the way with scientific progress. Adding to the storehouse of human knowledge takes financial resources, and there is no guarantee of a return on investment, whether technical or cultural (an increase in scientific knowledge). Hence the impression of a technoscientific project that has proceeded nonrationally, almost by alchemy, in order to satisfy all the parties involved.

