making it impossible to predict any specific effects on humans. But we are confident that ongoing research will confirm that the hormonal experience of the developing embryo at crucial stages of its development has an impact on adult behavior in humans, affecting the choice of mates, parenting, social behavior, and other significant dimensions of our humanity.

Nevertheless, at the moment it is impossible to know whether hormone-disrupting chemicals are contributing to any of the disturbing social and behavioral problems besetting our society and, if so, how much. Each of these problems is immensely complex and the result of a variety of forces acting together. At the same time, studies with animals are clearly showing that disrupting chemical messages during development can have a lifelong impact on learning ability and behavior. Hormone disruption can increase the tendency toward a certain kind of behavior, such as territoriality, or attenuate normal social behaviors, such as parental vigilance and protectiveness. Given this provocative evidence, we should consider chemical contamination as a factor contributing to the increasing prevalence of dysfunctional behavior in human society as well.

Some might find irony in the prospect that humans in their restless quest for dominance over nature may be inadvertently undermining their own ability to reproduce or to learn and think. They may see poetic justice in the possibility that we have become unwitting guinea pigs in our own vast experiment with synthetic chemicals. But in the end, it is hard to regard such a chemical assault on our children and their potential for a full life as anything but profoundly sad. Chemicals that disrupt hormone messages have the power to rob us of rich possibilities that have been the legacy of our species and, indeed, the essence of our humanity. There may be fates worse than extinction.

Our Stolen Future
Theo Colborn et al.
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FLYING BLIND

EVERY CREATURE INEVITABLY ALTERS ITS SURROUNDINGS AS IT SCRAMbles to make a living. This is a part of life and has been so since microorganisms first began changing the chemical makeup of the Earth's atmosphere some two billion years ago.

Humans have been no different. We have hunted game, gathered fruit, cleared forests, drained wetlands, planted fields, dammed rivers, built cities, soiled streams, constructed factories, and thrust railroads across desolate plains. But for most of the few million years that humans have trod upon the planet, our impact has been discrete. We have transformed one valley but not the next; one watershed but not its neighbor; one county but not a continent. The scale of human changes has always seemed slight when compared with that of the natural forces shaping the planet.

Today this has all changed. The twentieth century marks a true watershed in the relationship between humans and the Earth. The unprecedented and awesome power of science and technology, combined with the sheer number of people living on the planet, have transformed the scale of our impact from local and regional to global. With that transformation, we have been altering the fundamental systems that support life. These alterations amount to a great global experiment—with humanity and all life on Earth as the unwitting subjects.

Synthetic chemicals have been a major force in these alterations. Through the creation and release of billions of pounds of man-made chemicals over the past half century, we have been making broadscale changes to the Earth's atmosphere and even in the chemistry of our own bodies. Now, for example, with the stunning hole in the Earth's protective ozone layer and, it appears, the dramatic decline in human sperm counts, the results of this experiment are hitting home. From any perspective, these are two huge signals of trouble. The systems undermined are among those that make life possible. The magnitude of the damage that has already occurred should leave any thoughtful person profoundly shaken.

It is equally disturbing that the global scale of the experiment makes it extremely difficult to assess the effects. Over the past fifty years, synthetic chemicals have become so pervasive in the environment and in our bodies that it is no longer possible to define a normal, unaltered human physiology. There is no clean, uncontaminated place, nor any human being who hasn't acquired a considerable load of persistent hormone-disrupting chemicals. In this experiment, we are all guinea pigs and, to make matters worse, we have no controls to help us understand what these chemicals are doing. Faced with the question of whether synthetic chemicals are contributing, for example, to learning disabilities, researchers have typically set up studies comparing contaminated children with an uncontaminated control group. Tragically, no children today are born chemical-free. In the search for relatively uncontaminated control populations, researchers have ironically discovered the appalling universality of this contamination. Even Inuits living a traditional lifestyle in remote regions of the Arctic have not escaped. The pollution has come to them.

The early results from this unintended experiment raise thorny and profound questions that reach far beyond the immediate challenge of managing and eliminating the chemicals that have caused

these problems. It is no longer sufficient to look for the next round of substitutes for existing chemicals, for a new generation of supposedly less damaging synthetic compounds. The time has come to shift the discussion to the global experiment itself.

What has this breathtaking plunge toward new technologies wrought? It has yielded unparalleled health, luxury, and comfort for some significant minority, at least, of the human population, but the technologies themselves have often had a dark side that has only become evident decades later, after it is too late to recall them. When questioned about the risks of releasing genetically engineered organisms into the environment, one of the world's preeminent molecular biologists saw no reason for hesitating. He told a group of journalists that our society has to "be brave" and forge ahead with new technologies despite the uncertainties. But what seems brave to some seems foolish to others.

If the ozone hole and falling sperm counts are clear warnings about the perils of proceeding with business as usual, where do we go from here? Is there any way to anticipate the consequences of our technology? If we remove hormone-disrupting chemicals from the market, how can we be sure that their replacements won't be creating other nasty surprises thirty years hence? Is there any way to stop the experiment with our children and the environment, an experiment that has been an accepted way of life in the twentieth century? Or is the prospect of such hair-raising surprises a part of the Faustian bargain we have made in exchange for health, comfort, and convenience?

When stopped short by one of these nasty surprises, such as the ozone hole, we have typically set about in search of "safe" substitutes—a quest based on the unarticulated assumption that synthetic chemicals can be put into the environment with impunity if chemical companies and government regulators screen them properly for safety. But proposed substitutes that may be "safe" for the ozone layer pose other hazards, it turns out, through their capacity to trap heat and accelerate greenhouse warming.

A similar pattern emerges in the history of pesticide oversight. Like generals, pesticide regulators are always and perhaps inevitably fighting the last war. Again and again, they have vetted chemicals for the most recently recognized hazard only to be blindsided by dangers they never thought to anticipate. They judged DDT by the hazards of the previous generation of pesticides—the acutely toxic arsenic compounds that could bring sudden death to farmers or those unfortunate enough to eat food contaminated with residues. Only after DDT had been spread as liberally as talcum powder across the face of the Earth did we realize that DDT brought death as well, but in a different way. When concerns emerged about the persistence of DDT and its impact on wildlife, regulators imposed controls, and less persistent compounds such as methoxychlor came onto the market. Now we know that methoxychlor, which is still in wide use, disrupts hormones.

There is a need to screen the thousands of chemicals in commerce and to eliminate those that disrupt hormones. If we proceed, however, as we have in the past, we will simply spread a new generation of substitute chemicals across the face of the Earth. It will be yet another chapter in this reckless experiment. Though these new chemicals may be safer from the perspective of hormone disruption, it is likely they will have other unforeseen consequences—some relatively trivial and some perhaps as serious as the ozone hole.

Judging from past experience, it may take a generation for the next nasty surprise to emerge. When it comes it will show up where we least expect it. Thirty years from now, our children may be struggling to stem another serious assault on the systems that support life. Perhaps the next surprise will show up in the soil, one of the least appreciated parts of our life-support system. The consequences would be dire indeed if human activities were to seriously undermine the soil's ability to recycle nutrients—a process of recycling and renewal that depends on a myriad of bacteria, fungi, and insects. The safer bet, however, is that the surprise will be something never even considered. If anything is certain, it is that we will be blindsided again.

This caution does not arise from any propensity for pessimism or dislike of technology. It arises from the very nature of our global experiment and from our inescapable ignorance, which makes it impossible to foresee consequences or guarantee safety. The dilemma

is simply stated: the Earth did not come with a blueprint or an instruction book. When we conduct experiments on a global scale by releasing billions of pounds of synthetic chemicals, we are tinkering with immensely complex systems that we will never fully comprehend. If there is a lesson in the ozone hole and our experience with hormone-disrupting chemicals, it is this: as we speed toward the future, we are flying blind.

We can screen chemicals for hazards that have already confronted us such as hormone disruption and ozone depletion, but the next nasty surprise will happen because we do not even know what questions to ask. Nothing illustrates this point better than our experience with two now infamous chemicals—CFCs and DDT.

Like DDT, ozone-depleting chlorofluorocarbons (or CFCs) were touted as one of the safest substances ever invented, and like DDT, they seemed one of the unalloyed blessings of progress when they were first synthesized by Thomas Midgley Jr. in 1928. Midgley, one of the pioneers in industrial invention, developed CFCs in response to the demand for a safer alternative to the toxic and flammable chemicals used as coolants in refrigerators. In 1941, he received chemistry's highest award for his work, the Priestley Prize. Making his acceptance, Midgley, a man with an incorrigible theatrical streak who loved to play Mr. Wizard, could not pass up the opportunity to treat the audience to one of his favorite demonstrations. He poured CFCs into a shallow dish, inhaled as the refrigerant vaporized, and held his breath as he lighted a candle. Then he exhaled, extinguishing the candle triumphantly—again demonstrating that the chemical was neither flammable nor toxic to humans and, therefore, unquestionably safe.

CFCs were on the market for more than forty years before the first shadow of suspicion fell on them. In 1970, James Lovelock, the maverick scientist and inventor who would later become widely known for the Gaia hypothesis, began to make measurements of the atmosphere with his new invention—an electron capture detector that increased the sensitivity of the gas chromatograph a thousandfold. With this powerful new tool, it was now possible to detect minute traces of synthetic chemicals in the atmosphere that are present in concentrations of parts per trillion. Lovelock soon began to find CFCs everywhere he looked, even in samples taken from a ship that cruised to the southern tip of South America—a sign that CFCs were now ubiquitous in Earth's atmosphere.

By 1972, Lovelock had communicated his findings to Raymond McCarthy, an official at Du Pont, the world's leading manufacturer of CFCs. Apparently concerned by the news that CFCs were accumulating in Earth's atmosphere, McCarthy called a meeting of the CFC manufacturers in the chemical industry to discuss "the ecology of CFCs in the environment." At the same time, he commissioned several studies to consider the reactivity of CFCs.

Du Pont was no doubt reassured by the findings from these studies, which concluded that CFCs did not appear to break down into toxic or reactive compounds that might harm people or cause environmental problems. Unfortunately, however, the eyes of the researchers were fixed only on the lower atmosphere. It appears no one even considered possible threats to the ozone layer high up in the stratosphere. That question would surface two years later in June 1974, when chemists Sherwood Rowland and Mario Molina published their now famous paper in the journal *Nature*, describing how CFCs would eventually make their way to the stratosphere and attack ozone. Ultimately Du Pont would phase out its manufacturing and distribution of CFCs. And in 1995 Rowland and Molina were awarded the Nobel Prize for this research.

The history of DDT contains a similar paradox. The pesticide was considered such a milestone on the road of human progress that its developer, Paul Müller, was hailed as a savior and awarded the Nobel Prize in 1948. In the short term, the chemical did seem wondrous. It killed insects while posing little direct threat to humans, and by eliminating the mosquitoes that carry malaria, it saved countless lives. But like CFCs, DDT was at the same time invisibly attacking the foundation of life.

In the end, what we did not know proved to be more important than what we did know. In the end, what we thought were the safest chemicals proved to be among the most dangerous. And when the ozone depletion predicted by Rowland and Molina appeared, it far exceeded the worst-case scenario that atmospheric scientists had forecast.

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The situation confronting us is not one that lends itself to easy prescriptions or simple answers. Our current economy and civilization are built on a foundation of fossil fuels and synthetic chemicals. According to one chemical industry estimate, chlorinated synthetic chemicals and the products made from them constitute forty-five percent of the world's GNP. If it has taken fifty years to work our way into this dilemma, it will almost certainly take just as long or longer to find our way out of it.

As we look toward the future and think about charting a new course, it is critical to begin with a clear-eyed view of our situation. As the experience over the past half century has demonstrated, there is no way to put large quantities of man-made chemicals into the environment without exposing our children and ourselves to unknown risks. Many of these synthetic compounds may prove harmless, but others may not. We must face the fact that there is no way to guarantee the safety of synthetic chemicals, even those that have been on the market for decades. CFCs had been in broad use for fifty years before the ozone hole was discovered over Antarctica. The lag time before effects emerge in vast, complex systems can give a false sense of safety and increase the opportunity for catastrophe.

We must be ever mindful that for all the advances in science, we still have only the most general understanding of the life systems on which we have been experimenting—whether our own bodies or Earth's atmosphere. At the time that CFCs were invented, scientists did not understand the ozone layer or its importance in shielding the Earth from ultraviolet radiation. That came three years later through the work of a British scientist, Sydney Chapman. DDT and other hormone-disrupting chemicals were on the market for two decades before researchers began to fathom the mysteries of the hormone receptors and even longer before they discovered that synthetic chemicals could mimic hormones and engage those receptors.

Ultimately, the risks that confront us stem from this gap between our technological prowess and our understanding of the systems that support life. We design new technologies at a dizzying pace and deploy them on an unprecedented scale around the world long before we can begin to fathom their possible impact on the global system or ourselves. We have plunged boldly ahead, never acknowledging the dangerous ignorance at the heart of the enterprise.

Such arrogant presumption may be an ineradicable part of human nature. The ancient Greeks called it hubris. Throughout human history, humans have risked the unknown, courting both success and catastrophe. What differs now is the stakes, the magnitude of possible mistakes. Our activities no longer involve just one village and its neighbor, one valley or the next. The scale of human activity means that these experiments engage the planet.

As we race toward the future, we must never forget the fundamental reality of our situation: we are flying blind. Our dilemma is like that of a plane hurtling through the fog without a map or instruments. Instead of being able to provide a reliable radar system, scientists are peering through the cockpit window trying to warn of any obstacles ahead. And usually, the most they can say is that the dark mass looming into view might be a cloud bank. Or then again, it might be a mountain.

So what do we do? Land the plane as quickly as possible, slow down, or proceed full speed ahead because it would be incredibly expensive and disruptive to cancel this trip?

These kinds of questions confront us today as we grapple with the consequences of our half-century experiment with synthetic chemicals. When confronted with a troubling environmental problem, the first impulse has been to appoint a panel of experts in the hopes that they can give us the right answer. Scientists can certainly provide invaluable guidance, as the work described in this book amply demonstrates. But science alone does not always have the answer.

Deciding on a wise course involves a host of considerations and, most of all, value judgments. It is not just a question of the quality of science describing the problem but also of how we see the risks and how much risk we are willing to entertain. Consider the convenience that endocrine-disrupting plastics bring to human lives against the risks they entail. If all that is at stake is the survival of a single gull colony, it may be wise to wait for further scientific study before embarking on an effort to reduce exposure. If, on the other hand, it is a question of decreasing human sperm counts, prudence

may dictate acting immediately rather than waiting to see whether the downward trend continues.

Phasing out hormone-disrupting chemicals should be just the first step, in our view. We must then move to slow down the larger experiment with synthetic chemicals. This means first curtailing the introduction of thousands of new synthetic chemicals each year. It also means reducing the use of pesticides as much as possible, for these compounds are biologically active by design, and billions of pounds are deliberately released into the environment each year.

But these steps merely deal with the problems of which we have some inkling, however crude. They help not at all with the next generation of surprises, the next unexpected results from our massive alterations of the planetary system. In this light, eroding ozone and falling sperm counts cast dark shadows across the human future. They confront us with the unavoidable question of whether to stop manufacturing and releasing synthetic chemicals altogether. There is no glib answer, no pat recommendation to offer. The time has come, however, to pause and finally ask the ethical questions that have been overlooked in the headlong rush of the twentieth century. Is it right to change Earth's atmosphere? Is it right to alter the chemical environment in the womb for every unborn child?

It is imperative that humans as a global community give serious consideration to this question and begin a broad discussion that reaches far beyond the usual participants—the chemical companies, government regulators, farmers, economists, scientists, and environmental groups. This discussion must engage teachers and parents, physicians and philosophers, artists and historians, spiritual leaders such as the Pope and the Dalai Lama, and others who reflect the richness and diversity of human experience and wisdom.

On a more practical front, we need to explore whether it is possible to discontinue the global experiment without abandoning synthetic chemicals. Are there principles of chemical design and use that would allow us the benefit of innovative materials without undue exposure and risk? Considering the skyrocketing human population and a daunting agenda of global environmental problems, it seems impossible to turn the clock back half a century and return to a material horizon bounded by wood, steel, and glass. At the same time, any such exploration must always bear in mind that it is impossible to anticipate nasty surprises. The goal must therefore be to keep human and environmental exposure to an absolute minimum. How synthetic chemicals fit into a sustainable, healthy future remains unclear.

If it is too early to describe the precise road, it is possible to signal the direction for this journey. For the past half century, the commerce in cheap, abundant synthetic chemicals has shaped agriculture, industrial processes, economies, and societies. It is impossible to imagine the great migration of Americans to the steamy Sun Belt without the CFCs that made it possible to air-condition homes, cars, and public buildings. Similarly, the new generation of synthetic pesticides that swept onto the market after World War II aided and abetted the growth of specialized industrial farming that depended exclusively on a chemical arsenal for pest control and abandoned agricultural practices such as crop rotation, carefully timed planting, or other methods to keep insects in check. The chemical age has created products, institutions, and cultural attitudes that require synthetic chemicals to sustain them.

The journey to a different future must begin by defining the problem differently than we have until now. As a general rule, the framing of a problem limits solutions more than a lack of ingenuity or technology. The task is not to find substitutes for chemicals that disrupt hormones, attack the ozone layer, or cause still undiscovered problems, though it may be necessary to use replacements as a temporary measure. The task that confronts us over the next half century is one of redesign. When forced by the phaseout of CFCs to reconsider the use of solvents when manufacturing electronic circuitry, one research effort in the United States found a way to eliminate the need for CFCs or any other solvent by redesigning the soldering process. Following such examples, we need to redesign not only lawns, food packaging, and detergents, but also agriculture, industry, and other institutional arrangements spawned by the chemical age. We have to find better, safer, more clever ways to meet basic human needs and, where possible, human desires. This is the only way to opt out of the experiment.

As we work to create a future where children can be born free of chemical contamination, our scientific knowledge and technological expertise will be crucial. Nothing, however, 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. We owe that much, and more, to our children.