Introduction

The Argument

People in the age of science and technology live in the conviction that they can improve their lives because they are able to grasp and exploit the complexity of nature and the general laws of its functioning. Yet it is precisely these laws which, in the end, tragically catch up with them and get the better of them. People thought they could explain and conquer nature—yet the outcome is that they destroyed it and disinherited themselves from it.

—Vaclav Havel, "Politics and Conscience"[1]

In the next month, my wife, Margie, and I will have our first child. Our house is still quiet, for a few more weeks at least, as we wait—endlessly, it seems—for the baby's arrival. Under the surface, however, a host of questions roils: about the delivery, the baby's health, how his personality will develop, what life he will lead, the kind of world he will inhabit. We are ready for some answers, but the baby stubbornly holds out, unwilling to provide them on anyone's schedule but his own.

There are some things I already know about the baby and his history, however, that I might prefer never to have learned. I know that my semen contains scores of pollutants that may have damaged the DNA I contributed to the baby. I know that Margie, over the course of her life, has accumulated hundreds of industrial compounds in her tissues, and these substances have crossed the placenta and entered the baby's bloodstream. I know that these chemicals are flushed out of the body by breast-feeding, so the baby will get even higher doses after he is born. And I know of an emerging body of evidence that exposure to trace amounts of these compounds early in life can cause a range of subtle and severe problems, from cancer to reduced IQ, from infertility to a compromised immune system.

Some kinds of permanent damage may not become manifest until a child reaches adulthood.

Our baby is no different in this way from any other in today's world. Both Margie and I grew up in pleasant suburbs, reasonably far from major pollution sources. Neither of us works in chemical-intensive industries. So how did we get so contaminated? Through the food supply, the air, and the water we all share. We live on a planet that has become the repository for the products, emissions, and wastes of modern industry. Since about 1940, the production of synthetic organic chemicals in the United States has grown more than thirty-fold.[2] Over 70,000 industrial chemicals are now synthesized and sold on the market, some in amounts over a billion pounds per year.[3] Many are resistant to natural degradation processes, so they gradually accumulate in the environment and are distributed across the globe on currents of wind and water. As a result, a cocktail of hundreds or thousands of man-made chemicals can now be found absolutely anywhere on the planet, from the deep oceans to the North Pole, from the Mississippi River to our own bloodstreams.

The result is a dizzying array of environmental problems that have filled the news since the 1960s: DDT and the decline of bald eagles; toxic waste at Love Canal; cancer among Vietnam veterans exposed to Agent Orange; chloroflourocarbons and the ozone hole; PCBs in polar bear tissue; herbicides in groundwater throughout the Midwest; dioxin in fish downstream from pulp and paper mills. For many people, the hazards seem overwhelming in number, complexity, and the technical expertise necessary to understand them. Solutions seem even less accessible; the apparently sophisticated environmental laws of industrialized countries, with their byzantine and costly regulations, have failed to halt the tide of contamination.

From another perspective, however, the situation is far simpler than it first seems. The litany of problems listed above—and hundreds of less infamous but just as serious hazards—all involve chemicals of a single class, called organochlorines because they are organic (carbon-based) chemicals that contain one or more chlorine atoms. Not all pollution is due to organochlorines; some metals and nonchlorinated synthetic organic chemicals that do not contain chlorine also pose public health threats. But organochlorines dominate virtually all official and unofficial lists of hazardous pollutants in the environment, wildlife, and human tissues.

These pollutants all arise from a single root cause: the industrial production, use, and disposal of chlorine gas and chemicals derived from it—a family of processes called chlorine chemistry. Chlorine chemistry begins at a handful of large chemical facilities, where an extremely powerful electric current is passed through a solution of salt water. In chemical terms, salt is sodium chloride, a stable natural compound that circulates constantly through the ecosystem and our bodies, never combining with the organic matter of which we are made. Industry's electrical energy transforms salt's stable chloride ions into molecules of chlorine gas, a heavy, violently reactive, greenish gas that does not occur in nature. About three-quarters of the chlorine is used within the chemical industry as a feedstock for the production of over 11,000 organochlorines,[4] including plastics, pesticides, solvents, and chemical intermediates, virtually all of which are also foreign to nature. The remaining chlorine is sold to other industries for direct use—to pulp and paper mills as a bleach, for instance, or to sewage plants as a disinfectant.

For well-understood reasons, the chemistry of the chlorine atom gives chlorine gas and organochlorines useful properties, but these same qualities create enormous environmental problems. First, chlorine gas is highly reactive, combining quickly and randomly with whatever organic matter it encounters, so it is an effective bleach, disinfectant, and feedstock for synthesizing chemicals. Whenever chlorine is used, however, this same quality means that a diverse stew of hundreds or thousands of organochlorine by-products is formed incidentally.

Second, chlorination radically affects the chemical stability of organic chemicals, usually increasing it but sometimes decreasing it. Stable organochlorines are useful as plastics, refrigerants, and other applications in which long life is a virtue. Organochlorines that are stable in their intended use, however, are also persistent in the environment, resisting natural degradation processes for long periods of time—centuries, in some cases—so they gradually build to higher and higher concentrations in air, water, and sediments. When chlorination decreases a chemical's stability, on the other hand, it makes it more reactive, so some organochlorines make useful intermediates for synthesis processes in the chemical industry. Reactive organochlorines, however, are much more likely than their nonchlorinated precursors to be converted into highly toxic and cancer-causing forms in the body. The chemical effect of chlorination is therefore to increase, in one way or another, the hazard that a chemical poses.

The third effect of chlorination sounds innocuous but creates a terrible problem. Adding chlorine atoms invariably increases the ability of organic chemicals to dissolve in oils, so organochlorines make excellent solvents for industrial processes, like equipment cleaning and surface-coating operations, that involve oil-based materials. Once oil-soluble organochlorines are released into the environment, however, they accumulate in the fatty tissues of living things, a process called bioaccumulation. Bioaccumulative compounds gravitate from the ambient environment into the food web, magnifying in concentration as they move upward from tiny organisms to large predators. By the time they get to the top of the food web—the tissues of people, eagles, polar bears, and other species—some organochlorines reach concentrations many millions of times greater than their levels in the ambient environment.

Finally, chlorination virtually always increases toxicity. This effect occurs because modulating the persistence, reactivity, and oil solubility of a chemical changes its interactions with proteins and fats inside the body in a way that can disrupt the natural processes of physiology and development. These qualities make organochlorines effective pesticides, antibiotics, and pharmaceuticals. But organochlorines not intended to be poisonous tend to be toxic too; once in the environment, the properties that made them useful for killing unwanted organisms also injure humans and wildlife.

If chlorine chemistry were practiced on a minor scale, it might not present a major problem. Industry first produced chlorine gas around the turn of the century, but its use was rather limited until after World War II, when the chlorine industry began to grow at a breakneck pace. Today the world chemical industry produces an astonishing 40 million tons of chlorine annually, most of which is directed into the generation of organochlorine products and by-products. These substances enter the environment in a variety of ways. Some organochlorines, such as pesticides and the by-products of paper bleaching, are dispersed into the environment directly, while others—polyvinyl chloride (PVC) plastic products, for instance, or the complex hazardous wastes generated during its manufacture—enter the ecosystem indirectly through incinerators or landfills.

Because of their persistence and bioaccumulation, organochlorines now contaminate absolutely every inch of the planet. Even in remote polar regions, thousands of miles from any industrial source, a diverse cocktail of organochlorines can be found in the tissues of whales, seals, and polar bears. They contaminate our bodies too. Hundreds of toxic organochlorines are now present in the fat, mother's milk, blood, semen, and breath of the general human population — people subject to no unusual exposures in their workplace or communities. Airborne organochlorines have even drifted to the stratosphere, where the chlorine they contain reacts with the ozone layer, breaking down the shield that filters out the sun's powerful ultraviolet rays. After just six decades of large-scale chlorine chemistry, we can now say that every person and animal on earth is exposed to a complex stew of toxic organochlorines, from the moment of conception—even before, since the developing sperm and egg encounter these poisons too—until the closure of death.

As early as the 1950s, it was clear that a few organochlorines were extremely toxic, causing cancer and disrupting the body's organ systems at low doses. Only in the last decade, however, has the true scope of the problem begun to emerge. Several hundred compounds have now been tested, and virtually all organochlorines examined to date cause one or more of a wide variety of adverse effects on essential biological processes, including development, reproduction, brain function, and immunity. Some organochlorines cause these effects at extraordinarily low doses—in parts per trillion concentrations, a ratio equivalent to one drop in a train of railroad tank cars ten miles long.[5] Further, molecular biology has made possible the study of mechanisms of toxicity, revealing that organochlorines disrupt biological processes at the most fundamental levels. Some are potent mutagens, undermining the integrity of the genetic messages in our DNA, while others block communication between cells or interfere with the control of gene expression, turning genes on and off at inappropriate times and altering the natural course of development and physiology. A large number of organochlorines have been found to mimic or otherwise interfere with the body's natural hormones, the potent chemical signals by which multicellular organisms regulate their development and coordinate the unified function of their parts.

The implications of universal exposure to compounds that can have effects of this sort are profound. Every species on earth, including humans, is now exposed to organochlorines that can reduce sperm counts, disrupt female reproductive cycles, cause endometriosis, induce spontaneous abortion, alter sexual behavior, cause birth defects, impair the development and function of the brain, reduce cognitive ability, interfere with the controlled development and growth of body tissues, cause cancer, and compromise immunity. If we stopped all further pollution today, these compounds would remain in the environment, the food web, our tissues and those of future generations for centuries.

Contamination by persistent organochlorines thus poses a long-term, global hazard to human health and the environment. The scale and severity of the threat is rivaled only by the hazards associated with climate change, nuclear technologies, and the reduction of biological diversity (itself caused in part by chemical pollution). Even more sobering, a growing body of evidence suggests that global toxic pollution is already contributing to a slow, worldwide erosion of the health of humans and other species. By the time stratospheric ozone levels return to normal later in the next century, ultraviolet radiation is expected to have afflicted millions of people with skin cancer, blindness, and immune suppression. People and many wildlife species are routinely exposed to some organochlorines in amounts that are near, equal to, or greater than the doses that cause adverse effects in laboratory animals. There is little doubt that organochlorines in the food web are responsible for major die-offs and population declines in a variety of wildlife, from marine mammals to a host of fish and bird species in the Great Lakes, due to severe reproductive, developmental, and immunological impairment. Humans exposed to organochlorines in the workplace or by accident manifest similar symptoms, and a growing body of epidemiological evidence suggests that the background organochlorine exposures to which the general population is subject may be linked to the incidence of many kinds of cancer, immune suppression, infertility, and developmental problems like birth defects, low birthweight, and an impaired ability to learn. Exposure to organochlorines may thus be an important factor in the increases in many of these diseases and conditions that have occurred worldwide in the past several decades.

The hazards that organochlorines pose are fundamentally different from the health and environmental risks that current models of environmental regulation were designed to address, so they cannot be understood using the tools and concepts of the current system. These tools and concepts constitute a paradigm,[6] a total way of seeing the world, a lens that determines how we collect and interpret data, draw conclusions from them, and determine what kind of response, if any, is appropriate. Today's environmental policies embody an approach, which I call the Risk Paradigm, that attempts to manage pollution by permitting chemical production, use, and release, as long as discharges do not exceed a quantitative standard of "acceptable" contamination. This approach assumes that ecosystems have an "assimilative capacity" to absorb and degrade pollutants without harm. It also assumes that organisms can accommodate some degree of chemical exposure with no or negligible adverse effects, so long as the exposure is below the "threshold" at which toxic effects become significant.

The Risk Paradigm puts these assumptions into operation with the pollutant discharge permit, a license to pollute that sets maximum legal release rates of individual chemicals from individual facilities. Many other forms of chemical regulation, including pesticide registrations and occupational exposure limits, are also based on "acceptable" exposures. Regulators determine the permissible amount of single pollutants with a technique called quantitative risk assessment,[7] which works backward from the acceptable exposure level to calculate the maximum release rate that will ensure that this level is not exceeded. Industries comply with these limits by installing pollution control devices—such as filters, scrubbers, and evaporators—that capture pollutants at the end of the smokestack or discharge pipe and move them to a different place. In rare cases, the Risk Paradigm has taken more restrictive action like banning a chemical, but only when the evidence from epidemiological or ecological studies is overwhelming that a specific substance has caused severe health and environmental damage.

I might have called this model the acceptable discharge paradigm, or the pollution control paradigm, or the technocratic paradigm; all these names refer to essential elements of today's regulatory system. But calling it the Risk Paradigm gets at the heart of the current approach more clearly than any of these other terms. For one thing, risk assessment is this system's primary tool for assessing chemicals and setting acceptable discharges. More subtly, "risks" by definition are quantifiable probabilities of things that either do or do not happen; the word neatly captures the fact that the Risk Paradigm considers only those kinds of health damage that can be expressed in this narrow, numerical way, like cancer or birth defects, while excluding impacts—such as immune suppression, altered behavior, or reduced fertility—that are difficult to quantify and may affect every individual in a population to some degree. "Risk" also says something about the system's faith in the scope and reliability of scientific knowledge: risks can be reliably quantified, as the current framework presumes, only if we thoroughly understand how ecosystems and organisms are organized and how they may respond to human-induced interventions. The word also evokes the Risk Paradigm's reductionist view of the link between causes and effects in nature: risks by definition are created by specific activities or substances; synergy, feedback, unpredictable cascades of effects, and temporal changes in the sensitivity of an organism or ecosystem play no role in this approach. Finally, "risk" says something about the politics of the current system: in common usage, risks are voluntary things that people *take* in expectation of some benefit—when we bet on the stock market, for instance, or board an airplane, or eat fatty foods. People can reduce the risks they take, but there is no way to eliminate them entirely, since the only way to live a risk-free life is to do nothing at all. These connotations resonate in the Risk Paradigm's assumption that some "acceptable" amount of chemically-induced risks must inevitably be taken in the course of economic production.

This book is a case study of the failure of dominant models of environmental science and policy, and it argues for a fundamentally new approach. The Risk Paradigm is utterly ill suited to addressing the long-term, global health threat that organochlorines pose. Its inadequacy begins with the very concept of acceptable discharges: chemicals that persist in the ambient environment or in the bodies of living organisms build to higher and

higher concentrations over time, so acceptable discharges ultimately reach unacceptable levels. Further, recent research in toxicology and biology shows that for many effects—including cancer, developmental impairment, immune suppression, and some kinds of birth defects and neurotoxicity—there is no clear threshold of toxicity; any exposure, no matter how small, appears to contribute to the incidence or severity of disease and functional impairment. Moreover, pollution control devices merely shift pollutants from one place or environmental medium to another; they may reduce local pollution, but they do nothing to prevent global contamination.

Most important, the Risk Paradigm's focus on individual chemicals and individual dischargers offers no way to address the total pollution burden now accumulating in the environment. Thousands of individual facilities, each discharging the "acceptable" amount of thousands of different substances, together produce a cumulative global impact; the current system, focused only on the local parts, is and always will be blind to this problem of the whole. Synthetic chemicals are always produced in complex mixtures, and it is these mixtures, not neat packages of isolated chemicals, that cause health and ecological injury. Real organisms are simultaneously exposed to thousands of chemicals that interact in additive, inhibitory or synergistic ways, so an evaluation of the toxicity of a substance in isolation does not accurately predict the hazard it poses in the context of a myriad of other chemicals. Nor can epidemiology and ecology retrospectively link injury to individual substances; the tools available to these sciences can seldom untangle the complex webs of real-world cause and effect, and health damage is caused by exposure to complex chemical mixtures, which also interact with other causes of disease, like radiation and smoking. We can never fully comprehend environmental injury—or take adequate action to prevent more of it— through a lens that sees only singular substances acting in isolation.

The global hazard that organochlorines pose demands a new model for environmental policy. This approach, which I call the Ecological Paradigm,[8] focuses not on managing pollution but on preventing it. The new framework is founded on the view that ecosystems and organisms—and society too—are extraordinarily complex and dynamic systems in which innumerable parts are connected in webs of interdependency, multiple causality, and feedback loops, all of which change over time. The Ecological Paradigm seeks to protect these complex systems from both extreme local risks and the kinds of large-scale, long-term, subtle forms of damage that organochlorines and other chemicals can cause.

First and foremost, the Ecological Paradigm recognizes the limits of science: toxicology, epidemiology, and ecology provide important clues about nature but can never completely predict or diagnose the impacts of individual chemicals on natural systems. The implications for policy are obvious: since science leaves so much unknown, we cannot afford to make risky bets on its predictions or wait to protect health and the environment until we know for certain that some substance or technological practice has caused injury. Instead, we should avoid practices that have the potential to cause severe damage, even in the absence of scientific proof of harm. This rule, called the *precautionary principle*, is common sense: it says that we should err on the side of caution when the potential impacts of a mistake are serious, widespread, irreversible, and incompletely understood, as they are with the hazards of global toxic contamination.

In exhorting us to take early steps to prevent health and environmental damage, the precautionary principle says nothing about what kind of action is appropriate. To guide policy in practice, the Ecological Paradigm needs several additional principles. The first is a new standard for pollution regulations: called Zero Discharge, this rule would eliminate rather than permit the release of synthetic substances that are persistent or bioaccumulative and thus accumulate over time in the environment and our bodies. The second is a new technological approach for achieving environmental goals: Clean Production emphasizes front-end solutions, particularly the redesign of products and processes to eliminate the use and generation of toxic chemicals, before they need to be managed. Third is a new way of evaluating chemicals: Reverse Onus shifts the default state of environmental regulations from permission to restriction; the burden of proof, which now rests with society to prove that a chemical will cause harm, is shifted to those who want to produce or use a novel chemical. These parties must demonstrate in advance that their actions are not likely to pose a significant hazard. Chemicals already in commerce that do not meet this criterion should be phased out in favor of safer alternatives.

In the Risk Paradigm, a lack of data is misconstrued as evidence of safety, so untested chemicals are allowed to be used without restriction. Since the vast majority of chemicals have not been subject to toxicity testing, ignorance becomes the dominant factor in environmental decisions, and a generally laissez-faire system is the result. In contrast, the default state of the Ecological Paradigm is to avoid the use of chemicals that may harm health and the environment: we do not wait for proof of harm but always strive to reduce the use of substances that we have reason to believe may damage the environment. The Ecological Paradigm thus amounts to a program of continued reductions in the production and use of all synthetic substances, with priority given to chemical classes that are known to persist, or bioaccumulate, or cause severe or fundamental disruptions of biological processes.

By reversing the onus in environmental regulation, the Ecological Paradigm simply applies the standard that society now uses for pharmaceuticals—demonstrate safety and necessity before a drug is licensed for introduction into patients' bodies—to chemicals that will enter our bodies through the environment. Reversing the burden of proof would also set straight the twisted ethics of the current system, in which we mistakenly grant chemicals the presumption of innocence—a right that was created for people—while humans and other species are subject to a large-scale, multigenerational experiment of exposure to untested and potentially toxic chemicals.

In the case of organochlorines, reversing the burden of proof means that we address organochlorines as a class, presuming that chlorine-based products and processes are hazardous unless demonstrated otherwise. Industry and some analysts in government and academia have called this approach radical and unprecedented, but in fact it is neither. In making public policy decisions, we always choose, consciously or unconsciously, the appropriate level of intervention. Society does not try to address insect infestations by targeting individual bugs or traffic problems by regulating individual cars. In these cases, society has decided that it is more effective to focus on the systemic causes of problems rather than their manifestations at the level of individual entities, which are too numerous and uncontrollable to be micromanaged.

The same is true of organochlorines. Of the 11,000 organochlorines in commerce, only a small fraction have been subject to the most basic toxicity testing, and the full range of toxic effects is known for absolutely none. There are thousands more organochlorines formed as accidental by-products; the majority of these have not been chemically identified, so we do not even know their names, not to mention their toxicity and environmental behavior. Establishing chemical-specific regulations for every organochlorine would impose an impossible scientific and administrative burden on society, requiring centuries of study and administration before action could be taken to address a pressing health problem. Further, organochlorines are never created in isolation but are always formed in complex mixtures of products and by-products, so there is no practical way to control them one by one. In fact, all chlorine-based products and processes, at some point in their life cycle, result in the production and release of the most dangerous organochlorines, including dioxins and related compounds. Thus, even the least dangerous organochlorines, at some point in their life cycle, result in the incidental production of the most dangerous ones. If we want to restrict only the most extremely hazardous organochlorines, we must still address the full range of chlorine-based products and processes.

On the other hand, all organochlorines share a single root cause: industry's practice of chlorine chemistry. By applying Reverse Onus and Clean Production to the class of chlorine-based substances and technologies, we focus not on the thousands of individual organochlorines but on the much smaller number of processes that produce them. In this way, the Ecological Paradigm represents a shift from the micromanagement style that targets isolated chemicals to a macromanagement approach, which tackles classes of hazardous substances and technologies. Already, many pollutants—PCBs, lead compounds, and CFCs, for example—have been regulated as groups because they share hazardous characteristics or are produced by common sources. In fact, restrictions on assemblages of chemicals like these represent the most successful pollution policies since the 1970s. To apply this approach to the larger class of organochlorines is a significant extension of current practice, but it does not come out of the blue.

The chemical industry has objected that treating chlorine-based technologies as a class requires an unscientific, unsupported judgment that all organochlorines have the same properties, precluding any effort to evaluate individual chemicals specifically. First, I should be clear that the my argument does *not* assume that all organochlorines are equally hazardous. Each substance has unique properties, and the presence of chlorine does not in itself determine how toxic, persistent, or bioaccumulative a compound is. Instead, the effect of chlorination is to amplify the hazardous qualities of organic chemicals, sometimes to an extraordinary extent; organochlorines are virtually always orders of magnitude more toxic and bioaccumulative, and often much more persistent, than their chlorine-free precursors. For the purposes of public policy, then, there is a sound basis to treat chlorine chemistry as an environmentally dangerous activity that should be avoided whenever possible.

Second, the Ecological Paradigm does not preclude specific investigations of individual chemicals and processes; it merely changes the role of these evaluations in environmental policy. Both the Risk Paradigm and the approach I propose begin with a presumption—that the class of synthetic chemicals is safe or dangerous, respectively—and then evaluate specific substances that may represent exceptions. In structure, neither approach is any more scientific than the other. But consider the data: virtually all organochlorines that have been studied so far have been found to cause one or more adverse effects, so it is hardly likely that the rest will turn out to be safe. Presuming organochlorines hazardous thus better satisfies one of the most important criteria by which scientific theories are judged: that they maximize the explanatory power of the data and minimize ad hoc hypotheses—statements concocted after the fact to maintain a theory in the light of data that contradict it, such as, "Most organochlorines are safe; it's just a coincidence that almost all the ones we have so far examined are dangerous."

In practice, applying the Ecological Paradigm to organochlorines requires a simple but far-reaching program: the gradual phaseout of the production and use of chlorine and organochlorines and the phase-in of safer, chlorine-free alternatives. Organochlorines are now used in a wide variety of industrial applications, so this process, called a chlorine sunset, must be implemented with care. Sunsetting does not mean an immediate ban on chlorine, all its uses, and all its end products. Rather, it means a carefully planned process of technological conversion, a transformation of our industrial infrastructure that will take several decades. Sunsetting will require society to set priorities and time lines, make exceptions when necessary, evaluate substitutes, and take steps to minimize and address any economic dislocation that the program causes.

This proposal recognizes not only the shared properties of organochlorines but also their common source. Once chlorine gas is produced, a myriad of chemicals incompatible with the biological processes of complex organisms and the global ecosystem are formed and released to the environment, despite the best efforts of scientists and engineers to control them. Chlorine chemistry is like nuclear technologies: just as human intervention in the structure of matter unavoidably produces both desired and undesirable radioactive materials, the synthesis of chlorine gas inevitably results in the formation of toxic, persistent, and bioaccumulative products and by-products. Like the splitting of the atom, chlorine chemistry is an inherently dangerous technology of great power that interferes with the processes of nature at a fundamental level. Humans can harness this power but never completely control it. Chlorine chemistry is a technology we can and should choose to forgo.

I fully recognize the magnitude of a chlorine sunset and do not take lightly the technological and economic implications of a transition away from chlorine-based technologies. There are a few chlorine uses, such as some pharmaceuticals and some kinds of water disinfection, for which alternatives have not been developed or will take a long time to implement. For applications like these that serve compelling social needs, chlorine should continue to be used until substitutes are developed. But for the vast majority of chlorine uses, safer alternatives are now available, and technological innovation improves them with each passing year. Some of these processes are less expensive than organochlorines, and some are more costly; some substitute less toxic chlorine-free chemicals for organochlorines, and others rely on skilled labor or traditional materials. It will take time and money to convert to safer substitutes, but a well-planned transition will not impose an undue economic burden on society. In fact, experience suggests that less toxic processes are generally more efficient, create more jobs, and impose fewer externalized costs on society, such as cleaning up contaminated sites and treating people with chemically-induced

disease. We should thus see a chlorine sunset as an investment in a healthier and more sustainable economy.

The Ecological Paradigm implies considerable technological and policy change, but it is neither absolutist nor all-encompassing. Precautionary action requires a prima facie case, a sound reason to believe that a practice may cause serious or irreversible environmental damage, before measures are taken to anticipate and prevent harm. This book provides such a case—and more—for organochlorines, demonstrating by example how action on other classes of chemicals might be judged necessary or not. Further, once precautionary action is called for, a chlorine sunset would allow exceptions and a balancing of social interests if no alternatives are available for technologies that serve compelling human needs.

My point is not to elbow aside environmental concerns other than chlorine chemistry. Organochlorines are by no means the only pollutants we should be worried about,[9] and there are other ways we could organize our thinking about pollution issues. For instance, we might be concerned about chemicals that cause specific health effects, like carcinogenic substances or those that disrupt the body's hormones. Classifying chemicals by the problems they create, however, does not point to workable solutions, because pollutants that cause one kind of health effect are typically of many different types and come from diverse and unrelated sources. A policy to address endocrine disrupters, for example, logically begins with a program to identify all the substances that interfere with hormone action and then formulates a separate strategy to deal with each one. This strategy immediately bogs down in all the difficulties of the chemical-by-chemical approach. In contrast, a policy that addresses chemical classes focuses on the sources of chemical contamination, organizing the diverse hazards of synthetic chemicals in a way that leads directly to preventive action.

The fact is, organochlorines account for the majority of known endocrine disrupters; a large portion of identified carcinogens; a great number of chemicals that damage the nervous, endocrine, reproductive and immune systems; and virtually all of the world's persistent organic pollutants. The United Nations recently began negotiating an international agreement to address global contamination by persistent organic pollutants, and all twelve substances slated for immediate action are organochlorines. Organochlorines also dominate national lists of priority water pollutants, contaminants found at hazardous waste sites, and chemicals that contaminate the Great Lakes. If we want to prevent any of the major types of chemically-induced health hazards, sunsetting chlorine chemistry is an obvious priority. We can also see the specific policy I advocate as a case study: a chlorine phase out exemplifies the nature of action and assessment in an Ecological Paradigm, which can and should be extended to other classes of hazardous substances and processes.

As public and scientific concern about organochlorines began to grow in the early 1990s, the chlorine industry mustered its resources and began an ambitious public relations and lobbying counteroffensive. The effort was spearheaded by the Chlorine Chemistry Council (CCC), an arm of the Chemical Manufacturers' Association, along with the Chlorine Institute—a trade group of major producers and users of chlorine and organochlorines—and the Vinyl Institute, the association of companies that manufacture PVC plastic and its feedstocks. As of late 1994, the chlorine industry was spending about $130 million per year on its efforts to protect its products and reputation in the public arena.[10] The result has been a contentious debate over the hazards of organochlorines and the economic impacts of phasing them out. Throughout this book, I address the arguments of the CCC and its allies in detail, for two reasons. First, these statements represent the most comprehensive set of arguments that have been made against the position I take, so I see it as my responsibility to take them on directly. Second, one of my central concerns—on which I focus exclusively in the final chapter—is the relationship between science and policy. The words of chlorine's protectors are highly enlightening on this subject, providing insight into the ways that science, politics, and authority have been mixed in important and problematic ways in the debate over chlorine.

Confronted with calls for a chlorine phaseout, for example, the chemical industry and some scientists and government representatives have responded with the remonstrance that environmental policy must be based on "sound science." This sounds quite reasonable, though rather patronizing, if it means we should be well informed and rigorous in the use of scientific knowledge. But it turns out that "sound science" does not mean a way of asking questions but serves as short-hand for a specific answer: the continued use of chemical-by-chemical, risk-derived discharge limits. Any other approach, it is implied, is based on bad science or—even worse—emotion, fear, or some other suspect motive.

I address that charge in two ways. First, I present the information on organochlorines and assess whether it supports or refutes the assumptions of the two models for environmental policy. It is in fact the Risk Paradigm that turns out to be at odds with current scientific knowledge about chlorine chemistry, its products, and their effects on health and the environment. The Ecological Paradigm, on the other hand, was designed specifically to address the picture that ecology, biology, chemistry, and toxicology have painted of the structure and dynamics of organisms and ecosystems, the kinds of damage that synthetic chemicals can cause, and the ways that toxic substances are produced in industrial processes.

Second, we should not be misled that "sound science" requires society to put decisions about environmental policy in the hands of scientists. Decisions about pollution always encompass questions that science cannot answer. How much health or environmental damage is acceptable? How should health threats be weighed against the benefits of a technology? What alternative processes and materials are available that might prevent the pollution altogether? These are social questions that force us explicitly to consider ethics, values, and politics, as well as science. If we restrict the policy process to science alone, these issues are taken as settled, and the public, most of whom feel unable to evaluate scientific information themselves, is excluded from what should be a democratically determined decision. One of the most troubling elements of the Risk Paradigm is the way it limits debate to highly technical issues, like the quantification of toxicological thresholds and cancer risks, obscuring political and moral questions and protecting them from democratic discussion.

We can probe the idea of "sound science" even further. This book's analysis of the scientific claims deployed in the Risk Paradigm shows that political questions must be confronted not only in determining appropriate policies but also in assessing hazards themselves. Scientific knowledge that affects policy is always built on prior judgments about political and ethical issues. What kinds of health damage are worth assessing? Which species do we want to protect? What standard of proof should be satisfied before a conclusion is drawn? What constitutes a "negligible" risk? The science on which the Risk Paradigm is based presupposes answers to these questions that I believe most people would find unacceptable. In this way, not only the deployment but even the content of "sound science" turns out to involve judgments that should be exposed to democratic debate, not veiled behind a mask of scientific authority. The Ecological Paradigm acknowledges that science is a way of knowing about the world that is at once empirical and rooted in a political and social perspective. This new framework makes explicit the political questions that precede and pervade the creation of science in environmental decision making, and it provides means to settle them in a democratic context.

In the current system, the ethical issues may be hidden, but they are ripe. The technologies in use today are not inevitable facts of life but the products of conscious decisions. The world is contaminated with toxic chemicals because people and corporations have chosen to produce these substances, use them, and discharge them into the environment. We are exposed because society, by affirmation or omission, has given them leave to do so. Toxic pollution is by nature an ethical issue that involves the real and potential impacts of one person's actions on the well-being of others. Organochlorine pollution, global in scope and affecting many future generations, is a moral and political issue of great magnitude. The technologies used to meet society's needs and desires now have the potential to inflict far-reaching damage on the health and well-being of every citizen of the world. Choosing which technologies to adopt is thus a properly social decision that should be made explicitly and democratically. While the current system refuses to intervene in decisions about materials and production processes—insisting, at most, on the installation of tacked-on control devices—the Ecological Paradigm gives society the tools to begin a program of democratic technological development that meets its needs without sacrificing the health of future generations.

We have enough evidence now to come to this conclusion: the products and by-products of chlorine chemistry pose serious threats to the integrity of health and the ecosystem, and our current policies do not provide an adequate remedy. As the German government's Council of Environmental Advisors concluded in 1991, "The dynamic growth of chlorine chemistry during the 50s and 60s represents a decisive mistake in twentieth century industrial development, which would not have occurred had our present knowledge as to environmental damage and health risks due to chlorine chemistry then been available."[11] Today we have the knowledge we lacked then, and we must now act on it. Our failure to prevent the development of dangerous industrial practices in the past does not justify their continued use today.

The production of chlorine gas from salt sets the stage for the purposeful and accidental production of a vast number of novel chemicals that disrupt natural systems at their most fundamental level. The practice of chlorine chemistry has unleashed a host of unintended chemical and ecological consequences that our most sophisticated technologies are not capable of preventing. Chlorine chemistry is a Pandora's box, opened less than 100 years ago and still spewing its demons into the environment. While governments, cheered on by those who benefit from the open box, try to chase down each and every tiny demon that escapes, we miss the simplest and most obvious solution: close the lid.