# Managing Chemical Risks: The U.S. Experience

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**Abstract**

In response to criticisms of its safety, environmental discharges, and products viewed to be unsafe, the U.S. chemical industry has been a great deal of progress. I propose two goals for the industry:

- Eliminate mishaps that injure workers seriously or discharge harmful amounts of chemicals to the environment.
- Eliminate discharges that injure health or impose serious (non-transitory) environmental damage.

I also propose models that can be used to model the testing of potentially toxic chemicals, describe an industry program to reduce risks during transport, and describe risk communication efforts.

## 1. Introduction

The chemical industry has been a major force shaping the American economy and society in the past fifty years. The industry has contributed many good and many not so good things, from plastics and other modern materials to DDT, PCBs, and CFCs. Some groups have reacted with horror at the unfortunate aspects, proposing more detailed regulation or even banning the use of chlorine.

Society cannot enjoy the benefits of the chemical industry without incurring some risks to both health and the environment. Extreme proposals make no sense - society will not benefit from either eliminating the chemical industry or returning to an era where society played little or no role in the health and safety decisions of chemical companies. However, the potential damage from a mishap at a chemical plant or from the introduction of a new chemical is great. In order to increase safety, all developed nations have elected to impose greater costs on the operation of plants, use of highly toxic chemicals, and the introduction of new chemicals.

The chemical industry must set high safety and environmental goals. However, it is not reasonable to set goals of eliminating plant mishaps, discharge of toxic chemicals into the environment, or eliminating expose to toxic chemicals. No industry can operate with occasional mishaps, environmental discharges, or exposures. The industry should strive for the following goals:

- Eliminate mishaps that injure workers seriously or discharge harmful amounts of chemicals to the environment.
- Eliminate discharges that injure the health of workers or impose serious (non-transitory) environmental damage.

It is not possible to achieve zero mishaps or zero exposure. However, eliminating serious harm is possible and desirable. I will give a brief overview of the major issues confronting the chemical industry in 1999. I will describe, from an academic rather than industry standpoint, some of the steps that have been taken by the U.S. chemical industry to deal with these issues. I would not dare to draw lessons for the Japanese chemical industry, but I hope that this discussion will help provoke thought on possible actions and their consequences.

It is helpful to divide the issues into four phases: (1) The design of chemicals and decision to manufacture particular chemicals, (2) The manufacture and transport of chemicals, (3) the use of chemicals by companies and consumers and their end of life treatment, and (4) gaining the confidence of the public. I will discuss each phase. Finally, I will give a short description of some pollution prevention and sustainability research in the Green Design Initiative.

Paraceleus, the developer of modern toxicology, said that it is the dose that makes a poison. In other words, any substance is toxic in a large enough dose or benign in a sufficiently small dose. It is senseless to think of some chemicals as toxic and others as benign. Certainly there are major differences in the toxic potency of chemicals. However, the difference is a quantitative, not a qualitative one. The chemical industry can produce and use even the most toxic chemicals and not cause harm, as long as care is taken to reduce exposures to non-harmful levels.

## 2. Preventing Harm

For the first 2/3 of this century, most Americans believed that applied research and the introduction of new products was the key to growth of the economy and of personal income. "Better Living Through Chemistry" was the popular slogan of one large company. People were not so naive that they did not know that new products in general, and new chemicals in particular, sometimes caused great harm, e.g., aniline dyes. However, this harm was regarded as atypical, a small price to pay for the economic growth and prosperity. In the 1960s, public attitudes began to change. Environmental legislation in the 1970s required that new chemicals had to be tested and licensed by the Environmental Protection Agency before they could be produced. This switch to preventing possible harm posed considerable problems for the chemical industry.

When a new chemical causes cancer or other health problems, some unfortunate victims suffer but there is proof of a chemical's toxicity. In contrast, trying to prove that a new chemical will not harm health is essentially impossible. Toxicology has devised an array of animal models and in vivo and in vitro tests meant to predict toxicity to humans. Toxicologists have been clever in devising tests. However, there are no perfect tests that correctly classify all toxic chemicals as toxic and all benign chemicals as benign (Lave et al, 1988). In general a test has some chance of indicating that a toxic chemical is benign or that a benign chemical is toxic, type I and type II errors. Epidemiologists talk about the sensitivity of a test, the proportion of toxic chemicals that are correctly classified as toxic, and the specificity of a test, the proportion of benign chemicals correctly classified as benign.

A major difficulty with the animal models and test is that we rarely know the "information value" of a proposed test - its sensitivity and specificity or type I and II errors. Some tests will have high sensitivity and not so high specificity or vise versa. The characteristics of tests are important since there is a social cost to incorrectly classifying a benign chemical as toxic or vice versa. To select among tests, we must know the social cost a type I error (a false negative) and of a type II error (a false positive). The cost of the test and its sensitivity and specificity, together with the social cost of mistakenly classifying a benign chemical as harmful or a harmful chemical as benign determine the value of each test. Whether a test or battery of tests has value depends of the cost of testing, the sensitivity and specificity, and the social costs of being wrong.

Although this model is a standard one in decision analysis, it has not had a central role in testing the toxicity of chemicals. Estimating the cost of a test, its sensitivity and specificity, and the cost of a false positive and false negative are difficult. Usually, the cost of performing a test is known with reasonable accuracy. However, the sensitivity and specificity of a test are rarely known with precision. For example, for carcinogenicity testing, the lifetime rodent bioassay is assumed to be the "gold standard." However, the test yields only about 60% agreement between mice and rats. Since mice and rats are more biologically similar than either species is to humans, it follows that the lifetime rodent bioassay is about to predict human carcinogenicity less accurately than 60%. Government regulators find it difficult to accept the proposition that even skewing a test toward classifying a chemical as a carcinogen when it is not will not eliminate the possibility that some chemicals classified as benign are in fact carcinogens. Rather than choosing “conservative” tests and interpretations, regulators need to specify the social costs of false positive and false negative outcomes.

Last year, the Environmental Defense Fund challenged the chemical industry to collect basic toxicity data on all widely used chemicals. Of the several thousand chemicals with more than one million pounds of annual production, few have reasonably complete toxicity dossiers. The Chemical Manufacturer’s Association is taking the challenge seriously and trying to devise a program to provide the answers.

The simplest response would be to put all chemicals through a standard battery of tests. The cost would be billions of dollars. However, this response would waste resources and not provide an adequate basis for informed decisions about these chemicals. Testing potentially toxic chemicals is a relatively new field. Even in the 1960s, no tests for teratogenicity were routinely performed, resulting in the international problems with thalidomide. No tests can predict human carcinogenicity with great accuracy. Tests for reproductive toxicity are being developed. The point is that it would be a mistake to spend billions of dollars putting all chemicals through a standard battery of inadequate tests. A far better strategy would be to improve the quality and lower the costs of toxicity tests. Then, the chemicals could be put through this better battery of tests. We have lived with these chemicals for decades. There is no urgent need to perform all the testing in the next year or two. Furthermore, the cost of testing is so high, that comprehensive testing is unlikely to be repeated once more adequate tests have been developed. Spending billions for inadequate tests would prove costly to society because some benign chemicals would be classified as toxic and banned, because some toxic chemicals would be classified as benign and many people would be harmed by exposure, and because better tests would not be used when they were developed.

The chemical industry and Environmental Defense fund need to work out a strategy and timetable for testing the chemicals. The objective is more informed decisions, not some checklist attesting that all chemicals have undergone a uniform testing protocol. What toxicity information is most helpful for decisions regarding licensing, worker exposure, storage and shipping, and use? Are current tests adequate to produce this information? If so, focus on lowering the costs of these tests. If not, focus on developing new tests that will provide the desired information at reasonable cost. An Environmental Defense Fund, Carnegie Mellon University, University of Pittsburgh team is working on this approach to getting toxicity information to make informed decisions about chemicals. What is needed is a dynamic, rather than a static approach to testing. The goal of the program is not to test all of the chemicals on a uniform battery of tests as quickly and cheaply as possible. Rather, we need to focus on the information required for informed decisions. Since chemicals and new toxicity test are constantly being developed, we need a dynamic approach that explicitly accounts for how developments in early periods can improve information and lower costs in later periods. The speed of testing is determined by the value of the information gained now and the expectation of improved tests in the future. Since there is a great deal of experience with each of these chemicals, there is general information pertaining to the toxicity of individual chemicals. This suggests a Bayesian testing framework where the initial prior distributions are updated by testing. The current state of knowledge and knowledge of the information content of tests would determine whether testing was worth while with current tests or whether it was better to wait for improved tests.

### 3. The Value of Mechanistic Research on Chemical Toxicity

Recently, I undertook a study for the Chemical Manufacturer's Association to evaluate the value of basic research on chemical toxicity at the Chemical Industry Institute of Technology. With the help of scientists from both industry and the Chemical Industry Institute of Technology, I selected three chemicals for intensive review. For each of these chemicals, the Chemical Industry Institute of Technology research had shown that existing animal models were not predictive of human health effects.

The first part of the study was to assess the role of the Chemical Industry Institute of research in current understanding and regulatory actions concerning the chemicals. For each of the three chemicals, we found that the Chemical Industry Institute of Technology research had played a major role in understanding the mechanisms of action and thus giving a better estimate of the dose-response relationship at low doses. We also developed estimates of the cost of the Chemical Industry Institute of Technology research in general and for these chemicals. The third part of the study was to examine the markets for the three chemicals. If the chemicals were banned or regulated stringently, what would have occurred? Where a chemical was banned, we assumed that another chemical would be substituted. What was the difference in price and utility of the substitute chemical? When exposures to a chemical are tightly controlled, there is an additional cost for manufacturing and shipping.

The results of the study were that the US chemical industry, and the world chemical industry, would have lost a good deal of revenue and profit if the chemicals either were banned or regulated stringently. Consumers would have suffered because substitute chemicals were either more expensive or performed less well. The calculation of lost sales and lost profits showed that the industry and consumers would have suffered a great deal from this regulatory action. The Chemical Industry Institute of Technology research was able to show that more stringent regulation or banning these chemicals was not required to protect the health of workers and consumers. Thus, the contributions by US chemical companies to Chemical Industry Institute of Technology produced a large benefit to chemical companies and a still larger benefit to society more generally, since consumers were able to continue to enjoy thee use of these chemicals. While this study does not indicate that all research on the mechanisms of human toxicity is beneficial to chemical companies, it does show that basic research on mechanisms can be beneficial both to the industry and to consumers. It also indicates the characteristics of chemicals for which this research is likely to prove valuable to both the industry and consumers. Finally, the study indicates there is a large net benefit to society from developing better mechanistic information on chemical toxicity.

## 4. Responsible Care

A second general area of concern is the possible harm to society from shipping and storing toxic chemicals. Billions of pounds of toxic chemicals are shipped by pipeline, ship, rail, and truck and stored. The potential harm from these shipments and storage tanks is large. As the Bhopal incident made clear, having large inventories of toxic chemicals can be dangerous. However, there is little alternative to shipment and storage.

No matter how much care is taken in shipment and storage, collisions, leakage, and unfortunate incidents will occur. When problems occur, the key is rapid, informed response. Chemical companies in the USA and other nations have signed on to the Responsible Care program to help minimize the costs of unfortunate events. Facing up to this problem has done a good deal to make companies aware of their responsibility, improve shipping and storage practice, and reassure the public about the safety of chemicals.

In economic terms, the safety of chemicals is a public good. All chemical companies are benefited by greater real and perceived safety in the shipping and storage of toxic chemicals. However, each company realizes that it is expensive for it to be responsible. The situation is a "tragedy of the commons" or "prisoners' dilemma" situation. Actions by the chemical industry solved the problem of misplaced incentives. All participating companies acknowledge their responsibility and take appropriate actions. As a result, public confidence in the chemical industry has increased and companies have lowered the risks of mishaps during transportation and storage.

## 5. Risk Communication

For most of this century, the public was willing to deter to experts concerning safety in general and chemical safety in particular. Confidence in the competence and unbiased judgements of experts has ended. The public demands access to information so that it can make its own assessments. The lack of faith in experts has both good and bad implications for the US chemical industry. The good implication is that users are more knowledgeable and give information to chemical companies and regulators concerning what are acceptable risks. Thus, companies have better information is assessing "how safe is safe enough." The bad implication is that companies must publish extensive information of their environmental discharges, inventories, and the types of mishaps that could occur.

The most important environmental legislation in the USA is Title 3 of the Superfund Amendments and Reauthorization Act of 1986. This act requires that companies annually report their environmental discharges, inventories, and use of more than 600 toxic chemicals. Monsanto found the magnitude of its emissions embarrassing and pledge to voluntarily reduce air emissions by 90% in five years. In 1988 many chemical companies found themselves on the front page of the local newspaper, named as one of the ten worst polluters in the area. Companies have worked hard to repair their image by cutting their Toxic Release Inventory discharges and publishing annual environmental reports to show what they have accomplished. The act also required companies to set up and work with Local Emergency Planning Committees. These Local Emergency Planning Committees have access to all data on chemicals used, their toxicity, and quantity, and the plans that companies have made to handle emergencies. Although companies initially were extremely apprehensive about these Local Emergency Planning Committees, they have proven to be helpful.

This legislation has forced companies to think carefully about the risks that they impose on their workers and the community. In many cases, the result has been a marked decrease in environmental discharges. The legislation has also forced companies to think more carefully about communicating with the public about these risks and the steps that they can take to manage them. For example, most chemical plants in the US consider their facilities to be off limits to the public. They justify this policy by arguing that competitors could learn trade secrets from touring the plants, that those touring could be injured by a mishap, such as a toxic spill, or that their critics will only get more specific data to harass them.

All three criticisms are true, to some minor degree. However, they are exaggerated. When I visited the OxyChem plant in Niagara Falls, New York, the plant that generated the hazardous waste for Love Canal, I found a quite different view. Their plant is always open to those who want to tour it. They explained that the Love Canal episode created so ill will and suspicion toward the plant, that it could not be hurt further. They actively encourage people from the community and environmental groups to tour the facility. I was taken aback when they gave me a hard hat and respirator. They explained the use of the respirator and told me that if I heard a particular whistle, I was to put on the respirator immediately. Yes, they explained, they have toxic chemicals on site. But no one has been injured by leaks and they intended to keep it that way.

The new era of public communication has meant that the industry has tried to see how the public, even their critics perceive them (Fischhoff, 1995; Morgan et al, 1992). They have been sensitized to how the plants are viewed and what people are apprehensive about. In my judgment, the industry has been helped by this public communication, to the general benefit of society.

## 6. The Green Design Initiative

Carnegie Mellon University created a university-wide organization to conduct research on pollution prevention and sustainability. The Green Design Initiative spans the university since no one department has the range of skills required to work the problems.

We began with a $2 million grant from IBM. Some of my engineering colleagues talked about showing IBM how to design a "green" computer. We learned quickly that IBM didn't require our help in designing computers. However, their engineers announced that they were committed to designing and manufacturing more environmentally friendly products. However, they didn't have the tools to learn which of various designs was more environmentally friendly or how that design could be improved to make it still more friendly. This insight has shaped the Green Design Initiative. We have focused on developing tools that would allow designers and consumers to assess the extent to which a design, product, or use will impose less burden on the environment and health and be more sustainable. We have also applied these tools to particular products to test them.

One of our first efforts was to help interpret the Toxic Release Inventory data. The standard treatment of these data was to add together the total number of kilograms of the toxicants released to air, water, and as solid waste. This number has appeared in statements by EPA and in the headlines of many newspapers. It is misleading in three ways. The first is that the location of a release does affect the health and environmental damage. The second is that air emissions have much greater potential for human exposure than do discharges into properly licensed landfills of solid waste. The third is that the most toxic chemical among the 640 that must be reported is more than one million times more toxic than the least toxic chemical that must be reported. For all three reasons, adding together the mass of releases doesn't offer much information.

We addressed the second and third of these issues by weighting the environmental discharges by human toxicity and separating releases into the three categories of air, water, and solid waste (Horvath, et al, 1995). Our work shows that toxicity weighting can make a large difference in determining which plants in an area pose the greatest risk to people. For example, if general US chemical plants are high on the EPA list because the discharge large quantities of these toxicants. However, after weighting by toxicity, plants that handle heavy metals, such as lead and mercury, go to the top of the list because of the relative toxicity of these metals while chemical plants become less important because their discharges have lower toxicity.

The second major tool that we have developed is a new approach to life cycle analysis.

It is now generally recognized that the conventional (SETAC) approach to LCA has major difficulties. It is expensive, time consuming, and inherently controversial because of the need to place strict boundaries on the problem to keep it tractable (Portney, 1993). Our approach has been to start with a simple general equilibrium economic model, Leontief's input-output analysis (Lave, et al, 1995A; Hendrickson, et al, 1998). To the input-output matrix, we add a matrix of materials and energy use and a matrix of environmental discharges. The USA input-output table for 1992 has 500 sectors. Other government data enables to attach to each sector indices of the uses of various ores and fuels and the discharges of the criteria air pollutants, water pollutants, hazardous wastes, and all the Toxic Release Inventory pollutants. The resulting software is quick and easy to use. It provides a "screening" life cycle analysis in a few hours rather than many months. We will have this tool on the worldwide Web shortly and offer free access to anyone desiring to use it. A Japanese group apparently developed their version independently. I congratulate them on their achievement.

Let me mention two areas where we have applied our tools. The first is handling municipal solid waste. Germany led the world in requiring that packaging be recycled. However, many US cities required that municipal solid waste be separated and recycled. Our analysis found that much of this recycling actually harmed environmental quality and sustainability (Lave, et al, 1994). Recycling makes sense only where the material and fuels required for collection, separation, and recycling are less than what is required for virgin materials plus disposal of the waste material. We were able to show that municipal solid waste recycling in Pittsburgh used far more materials and energy than did disposing of it and making virgin materials. That allows us to address the question of when does recycling make sense. Our answer is that designing for recycling can make it much more attractive. Recycling of metals currently can make sense which recycling glass, low quality paper, and post-consumer plastics does not currently improve environmental quality or sustainability.

A second area that we examined is battery-powered cars. We were able to show that cars powered by lead-acid batteries will result in more lead being discharged into the environment that occurred when cars were powered by gasoline with tetra-ethyl lead. While the emissions of cars powered by leaded gasoline are likely to power much greater risks to people, no one wants to return to discharge large quantities of lead to the environment (Lave, et al, 1995B). In subsequent work, we calculated that half a million lead-acid battery powered cars in Los Angeles in 2010 would lower peak ozone concentrations from 200 ppb to 199 ppb while increasing national lead use (and presumably discharges) by 20% (Lave, et al, 1996). In my judgment, cars powered by batteries built from heavy metals (lead, cadmium, nickel) do more harm than good to the environment, save in special circumstances such as enclosed areas.

One major current project is an examination of alternative fuels for automobiles (MacLean & Lave, 1998). A life cycle view leads to interesting conclusions about the relative merits of gasoline, diesel, methanol and ethanol, natural gas, and hydrogen. Information on all this work can be found on our web page: www.ce.cmu.edu/Green Design/.

A Japanese group apparently developed their version independently. (Pub. Wks. Res. Inst., 1994., Kondo and Moriguchi)

## 7. Conclusion

The American chemical industry has made great progress in address safety and environmental issues. The industry was under great pressure to improve its performance in the 1970s. The industry has addressed the most important issues, built public confidence and is working toward solving its problem.

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