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WHAT GOES UP

THE GLOBAL ASSAULT ON OUR ATMOSPHERE

CHAPTER

2

Voices in the Wilderness

University of California at Irvine, December 1984

As Joe Farman began writing up the frightening figures of ozone loss from Halley Bay, six thousand miles to the west Dr. Sherwood Rowland was facing the reality that the CFC battle was all but lost. No one was listening, and a million tons per year of chlorofluorocarbons continued to churn into the atmosphere from an unconcerned world.

"The ozone layer problem? *What* problem? Didn't they solve that ten years ago?"

Rowland was not about to give up, of course. It wasn't in his nature. For that matter, neither was bitterness. Whatever frustration he felt—and he *was* frustrated—was contained beneath the even demeanor of his friendly smile and his eternal willingness to patiently explain even the simplest of things to the simplest of reporters, though fewer of them came around these days.

Rowland was a bear of a man, six feet five inches tall with huge feet, thinning hair, a broad, pleasant face—and the totally incongruous nickname "Sherry," a permanent touch of humor that often caught the newly introduced off guard.

"Uh, *Sherry* Rowland?"

"Better than Sherwood."

Not that Sherry wasn't known to the world of chemistry—and for the past eleven years, more than well known to those who deal with the atmosphere in various disciplines (atmospheric chemists, dynamicists, aeronomists, physicists, etc.). After all, it had been Sherry Rowland and his (at that time) postdoctoral research associate Dr. Mario Molina who had innocently stepped up to the bar of public opinion and political reality in 1974 and laid before the world an unbelievable theory: One of the most brilliantly conceived of chemical products—the exquisitely stable molecules known as halocarbons (chlorofluorocarbons), which could energize refrigerators and car air conditioners, blow plastic foam into useful shapes, clean electronic circuit boards, and safely propel the ingredients of underarm deodorant and hair spray cans—hinged on a deal with a chemical devil, the price for which could be the soul of the ozone layer several generations into the future.

"The *what* layer?"

Not too many people outside of atmospheric science, aeronautics, and astronautics had even heard of the ozone layer. A seemingly ethereal collection of bluish gas composed of three oxygen molecules bonded together in a very tenuous, easy-to-shatter ménage à trois, the ozone layer floats somewhere between eight and twenty-five miles above the planet, so those who were interested enough to ask were told. But in 1971, the world was presented with the sudden and well-publicized worries of several scientists that the exhaust gases from a worldwide fleet of high-flying supersonic transport aircraft (SST) could do substantial damage to the ozone layer, which would increase skin cancers among humans on earth. It was a new concept, and a new global threat to the environment. Suddenly TV networks were doing specials on the subject, and new, colorful descriptions were coined for the scientifically uninitiated. As one narrator explained it, "If you compressed all the ozone around our planet to normal sea level atmospheric pressure, the thickness of that layer would be only three tenths of a centimeter—around an eighth of an inch thick—an impossibly thin membrane of poisonous gas that, ironically, protects all life down here below." The public was told in various articles that the strange little molecules absorbed a type of ultraviolet sunlight (UV-B) that was harmful to human skin and the DNA molecules common to all living things on Earth.

It was the fight over the alleged linkage between skin cancer and airline equipment that first brought phrases such as "ozone layer" and "nitrogen oxides" into the language and public consciousness (nitrogen oxides were the worried-about molecular compounds left in the wake of high-flying jet engines that were thought to cause a catalytic reaction with ozone and lower the protective level of the gossamer-thin ozone layer).[1] But when the Boeing SST program was killed in 1971 (more for political and economic reasons than for any concern over ozone), the public's attention—and that of their senators and congressmen—largely drifted to other things. Richard Nixon had just accepted his second coronation as president, and a "third-rate burglary" at the Watergate in Washington was about to rivet the attention of the nation for several years to come. After all, there were no SST's being built, so there could be no threat to the ozone layer, right?

The atmospheric scientific community was not so easily convinced. Respected scientists such as Dr. Harold Johnston of Berkeley—a Southern gentleman of considerable charm and a steel-willed determination not to be cowed by political pressure—had been taking flak for several years for his statements about SST's and their potential for damaging the ozone layer. (He would later take great pride in finding he had been placed on President Nixon's "enemies" list for his opposition to the SST.) Though he handled it reasonably well, there was damage. A scientist's lifeblood is his reputation, and Johnston's had been sullied. He was an exceedingly careful senior chemist of stern ethical fiber, but he had been portrayed as a hotheaded radical for simply following his conscience and reporting his scientific conclusions. There was a bitterness in Johnston over it all, an edge that those who studied under his direction saw from time to time—young scientists such as Dr. Susan Solomon, who would later face similarly rarefied political/economic debates with the advantage of having Harold Johnston's experience to draw on. By 1984, Harold Johnston's battles had been all but forgotten outside the atmospheric chemistry community. But in 1973—when Sherry Rowland found himself pulled into the arena of the ozone debates for the first time—the wounds were still very fresh.

University of California at Irvine, December 1973

The sight of the quiet and contained form of Mario Molina hunched over his desk in the midst of a large office housing several other postdoctoral assistants was not unusual. He had held a similar pose many times over the previous weeks and months, working away with pencil, paper, and electronic calculator to chase down the answers to an interesting pure-science problem he had picked from among those Sherry Rowland had offered him. But this was not making sense. In fact, in some ways, it was simply too bizarre to be true. There *had* to be a rather monstrous error—but where?

Mario attacked the figures from a different angle, unaware that the speed of his numeric entries had increased just slightly, the clickety-clacking of the calculator keys barely audible, and all but unnoticed, in the clutter of the room.

Sherry Rowland had been quite pleased when Molina, a newly minted thirty-year-old Ph.D., agreed to join his group of postdocs at the relatively young Irvine campus. Irvine was a typical scientific teaching outpost, headquartered in a large, rectangular, six-story box of a building, and Molina's new position was blessed with comfortable anonymity (if modest pay).

Mario Molina came highly recommended from the Berkeley chemistry department. The son of the Mexican ambassador to the Philippines, he was an exquisitely educated young scholar of quiet demeanor, his closely cropped beard and short stature complemented by a quiet voice, intense eyes, dark hair, and kindly, almost shy appearance that seemed incongruous when he got to his feet to ably defend some point. The physical contrast between Mario and Sherry Rowland was almost stark. Rowland's imposing height and physique, his resonant voice and great stride were a counterpoint to the smaller measurements, quieter voice, and slight limp (from a youthful soccer injury) that characterized the new addition to Rowland's team. Yet Molina and Rowland were intellectual soul mates, both of intense intelligence and world-class scientific standards which held the promise of fruitful collaboration.[2]

Mario was not looking for notoriety any more than Sherry Rowland. But if these figures . . .

That was it. He had hit the wall. Mario Molina stuffed some of his calculations and papers in a folder and charged out of the office in search of Sherry Rowland. There was an error here someplace and he needed help in finding it.

The question they had decided to answer was quite simple and straightforward, uncluttered by political considerations or societal impact—or so Rowland had thought. "Where," he had asked, "do chlorofluorocarbons go when they escape at ground level?" When Freon (Du Pont's brand name for their premier CFC product) escapes during a recharge of a car air conditioner, or the halocarbon propellants are released from spray cans, where, and how high, do those molecules go before starting back down in some form? Chlorofluorocarbons are so stable they won't react with any product they propel or affect the skin of any human being they touch, but they have to go *somewhere.*

The CFC molecules were tiny packages of carbon, fluorine, and chlorine atoms bonded together which simply begin mixing with the rest of the atmospheric soup when released to the sky. Over time, the tiny molecules are swept up in the large-scale circulation of winds that carry them upward—a process known as turbulent diffusion.[3]

But precisely *when* do they come *down*?

Mario had chased equations around with his pencil and calculator until he was, quite frankly, a bit bored by the whole thing. Every possibility for the halocarbons to react in the Troposphere—the layer of atmosphere from the Earth's surface up to the thirty-five to forty-five-thousand-foot level, and the one in which almost all weather phenomena occur—ran into a dead end. Halocarbons were tough and resilient, and chemically snobbish. They wouldn't have anything to do with other molecules in the Troposphere, as far as he could tell, and there wasn't enough ultraviolet light from the sun coming through at those altitudes to break the molecules apart.

In effect, it was like a sky full of tiny plastic chips: The damn things were indestructible—at least in the Troposphere. They didn't react, they didn't "rain-out" (get swept to the ground by raindrops) because they wouldn't dissolve in water, they just stayed there, moving slowly upward in the circulatory patterns of global winds and turbulence.

Toward the Stratosphere.

Both of them had thought of stopping at that point and writing a paper on their findings. After all, they had answered their initial question quite thoroughly. Chlorofluorocarbons simply didn't break up in the Troposphere. In the language that normally described natural processes that remove polluting gases and particles from the atmosphere, they had been looking for a Tropospheric "sink," something that would in effect pull the CFC's from the atmosphere to end up harmlessly on the Earth's surface. But there was no sink for CFC's, other than the Stratosphere. They were now sure of that.[4]

"Well, we might as well be complete about it," they decided. There were chlorine atoms involved, and since they knew that chlorine was very reactive and would find several compounds in the stratosphere to react with, the question was *which* compounds at stratospheric temperatures and concentrations would attract the reactive attentions of the chlorine atoms released from CFC compounds. Among other molecules, ozone occupied those altitudes.

Sherry Rowland was not an atmospheric chemist, nor was Mario Molina. Neither was trained in dynamic theories of air transport, or meteorology. They were chemists. This airborne world was new to them and interesting because of that newness. Mario had begun his detective work by reading up quietly and thoroughly on things atmospheric, and was sufficiently sophisticated to know the nature of the Tropopause, the boundary layer that separates (and to some degree insulates) the Troposphere from the Stratosphere above. He was well aware, too, that in absorbing damaging ultraviolet light, ozone also absorbed heat, which was one of the principal reasons the temperature of the Stratosphere does some strange things: As altitude increases, the Troposphere gets colder, but the Stratosphere gets warmer.

If halocarbons didn't break up, fall out, or wash out of the Troposphere, they would continue being dispersed (by turbulent diffusion) into the Stratosphere, and eventually—when they were high enough and there was too little ozone above to filter out the extremely energetic wavelengths of UV radiation from the sun that can break the CFC molecular bonds—those bonds *would* be broken by photodissociation, and the once-indestructible man-made molecules would be reduced to various shards and pieces of molecular and atomic particles, including chlorine.[5]

In fact, chlorine, Mario determined, would end up within an interesting little molecule called chlorine monoxide (ClO).[6]

ClO is a free radical, which means it's promiscuous—it will mate indiscriminately with almost anything—especially another unstable molecule. (A free radical has an odd number of electrons, an essentially unstable arrangement that causes it to search endlessly for a way to react with other atoms or molecules.)[7]

When ClO collides with a free oxygen atom, it "gives" *its* oxygen atom to the stranger, forming a very stable marriage (O_2) with an even number of electrons. The newly formed O_2 goes floating happily away, leaving in its wake a single chlorine atom. And now the chain reaction begins.[8]

One chlorine atom, Mario discovered, would react with ozone, destroying successive molecules of ozone in a simple series of steps that always left the same chlorine atom in its original condition.

Chlorine is rapidly attracted to unstable ozone molecules (*if there are any in the gaseous neighborhood*), and on meeting one, will effectively steal one of the oxygen atoms from the ménage à trois. What was then an encounter between a single chlorine atom and the triple-oxygen formation known as ozone (O_3) now transforms to *another* stable O_2 molecule, and yet another promiscuous chlorine monoxide (ClO) molecule on the prowl for another free oxygen atom. When the ClO then hits an O, the product is a stable O_2 and a free chlorine atom once more. Like a fast-moving bachelor with a firm intention to avoid marriage, the chlorine transitions through two molecular relationships in each cycle, *destroying ozone*, leaving copious colonies of stable O_2 behind, always returning to its free state as a single chlorine atom on the prowl. ($ClO + O \rightarrow Cl + O_2$, then $Cl + O_3 \rightarrow ClO + O_2$, and finally, the ClO from that reaction: $ClO + O \rightarrow Cl + O_2$).

The loser is ozone. The peripatetic chlorine atom never meets an ozone molecule it doesn't destroy. It becomes the agent of destruction of ozone—a catalyst—but true to the definition of a catalyst, it promotes change without being changed.

Mario Molina worked through this reaction, though he had found nothing in the scientific literature about it.[9]

Okay, he figured, so we have a catalytic reaction in the stratosphere and ozone is the loser. Ozone is *always* being broken down and reformed anyway (O_3 bonds are broken by ultraviolet light leaving O_2 and O, which promptly hit similar partners to re-form O_3). So a few wild chlorine atoms take out a few thousand ozone molecule before they finally attach to some more complex molecule that takes *them* out of the picture (a sink at last for chlorine).

So what? The amounts were trivial, because the amount of chlorine was trivial. There were measurements showing only a tiny amount of CFC's actually in the stratosphere, though, of course, there was more of the stuff on the way up.

How much of the CFC's had been produced, he wondered? It seemed like an important question since, eventually, everything produced would reach the Stratosphere. Molina spent several days chasing down figures on the volume of chlorofluorocarbon production worldwide, and it was then that his figures began doing strange things. He had expected those figures to be trivial as well.

They weren't.[10]

"Sherry, we have to talk!" Mario caught up with a rumpled-looking Sherry Rowland in the hallway. His senior was getting ready to leave for a five-month sabbatical in Vienna—a Guggenheim fellowship he and his wife had been looking forward to—and the process of getting ready to go was obviously a strain. On top of it all, only about two weeks remained before Christmas.

But Sherry Rowland always had time for those who wanted to talk to him. The two scientists returned to the office and Mario explained the problem. Sherry knew instinctively there had to be an error, just as Mario did. After all, no one else had sounded any alarms about chlorofluorocarbons in the stratosphere, but the industry data showed that vastly more CFC's were being produced than any other trace gas that was known to be reactive with ozone. Obviously, the erroneous figures on Mario's pad indicated that the catalytic reaction of chlorine multiplied times the volume of chlorine that would eventually be injected into the Stratosphere by CFC's would have global consequences.

They wore down their pencils as they worked the figures over, punching the numbers into their calculators and retracing every step, looking for the big error that continued to elude them.

The next day they tried again, and by the end of the session—with no verbalization of the consequences of what they seemed to be seeing—they decided the error either didn't exist, or was too buried to find.

Sherry Rowland knew of Dr. Harold Johnston's deep involvement in the questions of ozone and atmospheric reactions, and he phoned him, outlining that they had found a chain. Rowland was somewhat startled to hear that the catalytic chain reaction was already known. What had *not* been found, said Johnston, was a sufficiently large source of chlorine in the Stratosphere to cause any real worry. There had been some concern that the space shuttle might inject chlorine, but those amounts seemed insignificant as well.[11]

"Well, we've found a chlorine chain *and* a chlorine source . . . we're trying to find out how much of this is known within the atmospheric science community," Rowland told him, and on December 27 they met in Johnston's Berkeley office.[12]

Harold Johnston went over the Rowland-Molina figures in great detail before informing the two men that they had indeed just found the first sizable source for free chlorine in the Stratosphere, and that he could find no errors in their work. Johnston knew what was ahead for the two. He had been through the mill already with the SST–ozone fight, and was still feeling the effects. Sherry Rowland was well thought of and possessed of an excellent reputation, and young Dr.

Molina was on his way. But the two of them were about to enter a new realm of public and professional scrutiny, and he gently tried to prepare them, recommending they make their case as thoroughly and completely as they could, because they would be tested and questioned by the best, the brightest, and the most desperate of all: the chemical giants themselves.[13]

Rowland asked Johnston if he would like to join them in writing up the results—and entering the spotlight. Johnston grinned and declined. He had already taken his turn in the barrel.

The two chemists returned to the airport that evening with a last question from Harold Johnston ringing in their ears: "Are you ready for the heat?"

Rowland now faced a dilemma: an impending departure with his wife, Joan, for what was to have been a relaxing change of pace for five months in Vienna. He had planned to use the time to search for interesting new projects, but now he'd be leaving one of the most profoundly challenging projects of his career. Yet, in Europe he would have some good opportunities to discuss the theory with other scientists (having previously scheduled several scientific talks) while Mario continued to refine the data back home.

The Rowlands caught their flight as scheduled, but within three days of arrival in picturesque Vienna, Sherry Rowland was working on a paper to report the CFC–ozone connection, which he quickly submitted to the British journal *Nature,* mindful of the need to get the word out to an endangered world as quickly as possible. If they were right, he told Joan, "it looks like the end of the world!"[14]

It took five long months for *Nature* to get around to printing the Rowland-Molina paper, and for the two men whose names were on it, the wait was an agony of expectation and uncertainty. All hell was certainly going to break loose when the paper appeared, or so they figured. Harold Johnston's warnings had not been lost on them, and they spent much of the intervening time—Mario in the lab at Irvine and Sherry in Vienna—boning up on the atmosphere and anything else that would help them defend their case.

At long last the edition carrying the "Rowland-Molina Theory" appeared in the June 28, 1974, issue—to thunderous silence.

When "papers" are submitted to scientific journals, they are judged initially by the editors, but then sent out to respected scientists in the same field for a critical professional review of the worth of the work, its accuracy, and its relevance to society and science (not necessarily in that order). It had taken about four months for various referees to look over the Rowland-Molina paper and, with raised eyebrows, try to figure out what to do with the California scientists' radical new off-the-wall theory, and the connection between CFC's and ozone.[15] The reaction among the general scientific population seemed much the same at first as that of the media: suspended animation, followed by puzzlement, incredulous rereading, and the tendency to disregard a pure theory put forth by mere chemists who had no experience in atmospherics.

Several months before the paper finally came out, Sherry Rowland had been called by an upset public relations man from the chemical industry who had read about the "ludicrous" chlorine-ozone theory in a leaked Swedish newspaper article.[16] He had also heard that the Rowland-Molina paper was using the world "Freon" instead of chlorofluorocarbons. What, the man demanded, had Rowland been thinking of to slander a respected trademark by connecting it with doomsday theories based on nothing but theoretical laboratory chemistry? Rowland promised to use the generic term from then on, but he figured the complaint would just be the opening round from the industry. Yet during the summer following the paper's appearance there were only the sounds of silence from the CFC producers, and by August, Rowland and Molina started to wonder whether the scientific community in general had even noticed.

They had. But it was the galvanizing realization about the delayed effect of CFC releases that froze many readers in their tracks with incredulous disbelief. How could *that* be true? Yet . . .

Almost all the chlorofluorocarbons that had ever been released into the lower atmosphere, according to Rowland and Molina, were still *in* the lower atmosphere, and going up. In fact, all of the stuff would eventually reach the Stratosphere in a process requiring decades. It was quiet and unemotional language, but the paper clearly pointed out that if the free chlorine did in fact have the predicted catalytic effect on the ozone layer, the effects could be expected to continue—and increase—for many more decades because of the impossibility of removing the slowly rising army of CFC's from the Troposphere. In other words, we could put it in the air, but we couldn't recall the millions of tons of the resilient little molecules, and that meant that if CFC–borne chlorine atoms ever started destroying the ozone layer with industrial-strength seriousness, the effects would be unstoppable for perhaps fifty years, and that was true *even if all CFC production was halted immediately worldwide*! Those were sobering words, even to those who doubted the chemistry.

To the chemical industry, the Rowland-Molina theory was a shocking assault on what had always seemed the perfect product, and they weren't going to take it lying down. There were six major U.S. producers of CFC's by 1974, and Du Pont Chemical had been the first, entering the commercial production phase back in the thirties.[17] Even though CFC's accounted for less than 2 percent of giant Du Pont's profits by 1974, the CFC lines were star performers, and as one scientist warned Sherry Rowland early on, Du Pont, for one, wasn't about to stop making them.

Du Pont, which prides itself on its reputation as a highly responsible company, had been careful about CFC's from the beginning, paying very close attention to any questions of CFC safety (if for no other reason than their suspicion that no product could possibly be so utterly safe and perfect).[18] In 1972 Du Pont had sponsored a two-year study on the overall safety of CFC's—a study that basically seemed to center on the Los Angeles basin. Three research groups were involved: one that tested CFC's in a smog chamber and concluded that CFC's would not react with L.A. smog; a second that measured UV interaction for CFC's (but stopped right in the middle of the stratospherically important UV-C range); and another that simply continued to measure CFC's in the atmosphere. The groups involved did not ask the same questions as Rowland and Molina, nor did they follow the same logic tree Mario Molina would later use, chasing the durable CFC's all over the Troposphere in calculations. Whether the effort was a serious attempt to find out if CFC's were dangerous or not, it was in the end completely ineffective.

Rowland and Molina had simply decided to look a bit further—or more precisely, a bit higher. The industry effort (orchestrated by Du Pont with what it described as the best of intentions) stopped at the Tropopause, and failed to consider the Stratosphere: the ultimate CFC dumping ground.[19]

During the summer of 1974, while Sherry Rowland and Mario Molina were waiting for the other shoe to drop, the two University of Michigan scientists who had worried about the space shuttle injecting reactive chlorine into the Stratosphere finally caught up with the Irvine chemists at a scientific meeting in San Diego. Ralph Cicerone and Richard Stolarski had read a preprint of the *Nature* article and were convinced the threat was real and immense.[20] The problem, though, was how to convince anyone else, especially policymakers who could take action. The conference ended with a small, local newspaper article about the worrisome Rowland-Molina findings, but the article failed to gain even the attention of the wire services. They would have to wait, apparently, for the publication in *Nature*.

Stolarski and Cicerone had no thoughts of getting themselves in the trenches in a shooting scientific war when they began poking into the Rowland-Molina hypothesis. They had simply thought that the questions of stratospheric ozone and shuttle-delivered chlorine were an interesting way of getting involved in atmospheric matters. They were neither advocates nor radicals. They were simply responsible scientists who were finding laboratory support for Rowland and Molina's conclusions, and in the course of normal scientific research, Cicerone and his University of Michigan group wrote up those supportive results and submitted them to *Science,* which scheduled the paper for a September 27 publication date. The magazine prepared a press release to go along with the paper, but even that wasn't to be used until the formal publication date.[21]

It was a classic dilemma for all four men. There was a moral imperative, and an ethical imperative, to speak out. Publishing probably wasn't going to be enough, but publication was the only formally accepted method for scientists. Yet, chlorofluorocarbons were so deeply ingrained in modern life—and especially in modern *American* life—anything less than major public attention focused on the problem would be insufficient to generate pressure on legislators.

In September, Sherry Rowland flew to Atlantic City to give the first major presentation on the issue to the monolithic and diverse American Chemical Society.[22] Maybe the paper hadn't yet stirred up a hornet's nest, but surely the ACS meeting—and any attendant press interest—might just get the necessary attention.

The "cause," however, was becoming more urgent than ever. Mario Molina had been refining the estimates of worldwide ozone loss, and they were becoming apocalyptic. The figures—based on a 10 percent per year increase in CFC production through 1990—predicted a 5 to 7 percent ozone loss by 1995, and a 30 to 50 percent loss by the year 2050![23]

That was galvanizing and controversial enough, but when Rowland tried to explain them in more human terms, he succeeded in ripping the lid off the Pandora's box that Harold Johnston had cautioned him would lead to excruciating "heat." A 30 to 50 percent ozone loss would mean a drastic rise in skin cancers, possible shift of climatic patterns because of less ozone to warm the Stratosphere, and possible crop damage. The lesson, said Sherry Rowland, was that what goes up has direct and damaging consequences, and CFC's, plain and simple, should be banned.

Banned! An *eight-billion-dollar-per-year industry* employing literally hundreds of thousands of Americans! That was unthinkable. Where was the evidence? This was *laboratory chemistry,* for crying out loud, with not a molecule of observational proof from the real world and the real atmosphere. Within the chemical community, at least, the presentation touched a blowtorch to some sensitive rear ends.

The media response was tepid at first. A few articles followed a press conference set up against industry wishes by ACS news manager Dorothy Smith, and their headlines were appropriately alarming, but as the weeks went by, more and more articles began to pay serious attention to the new theory, and what it might mean.[24]

Stolarski and Cicerone's research group, responding to the wire service coverage of the ACS news conference, announced their findings the next day by press release (their supportive paper was published in the American journal *Science* on September 27), giving Rowland and Molina substantial credibility and boosting the estimate of total ozone loss worldwide to 10 percent by 1985 to 1990!

Not to be outdone, Harvard atmospheric scientists Steven Wofsy and Mike McElroy (a flamboyant and combative scientist who had originally derided aspects of Stolarski's theories in Japan before the *Rowland-Molina paper came to light)* weighed in with ozone loss figures in the same general range in late September, gaining substantial national publicity in the process from the dean of American science reporters, Walter Sullivan of *The New York Times* (Sullivan mentioned Rowland and Molina only in passing).[25]

In England, the brilliant and fiercely independent atmospheric chemist James Lovelock (who devised the theory of

Gaia, which considers Earth a living organism with self-correcting and regulating abilities) was unimpressed. Lovelock had been the first scientist to actually detect the presence of CFC's in the atmosphere, and had proclaimed them of "no conceivable hazard," a position he began to rethink ever so slightly after reading the Rowland-Molina paper. "The Americans," he told a British newspaper (as reported by Lydia Dotto and Harold Schiff in their excellent 1978 book on the subject, *The Ozone Wars*), "tend to get in a wonderful state of panic over things like this. I respect Professor Rowland as a chemist, but I wish he wouldn't act like a missionary . . . I think we need a bit of British caution on this."

Lovelock, disregarding his own advice about being cautious with one's comments, went on to say that the Rowland-Molina controversy was "like the great panic over methyl mercury in fish. The Americans banned tuna fish and they blamed industry until someone went to a museum and found a tuna fish from the last century with the same amount of methyl mercury [occurring naturally] in it." (James Lovelock could be forgiven for not knowing the name of that "someone" scientist who thought to go find a museum fish was none other than Sherry Rowland.)

Despite Lovelock's reservations, and despite the rising volume of rumbled discontent and alarm from the chemical industry, the Harvard and Michigan papers (along with several other supporting findings) gave the Rowland-Molina theory enough momentum to spur some significant action. On October 8 the National Academy of Sciences decided to name Sherry Rowland, Harold Johnston, Mike McElroy, and two others to a committee to determine the seriousness of the ozone–CFC threat and to decide whether a full-scale investigation was warranted. As the panel prepared to meet, the CFC industry rushed to prepare its case against the wild, unproven, highly suspect hypothetical Rowland-Molina theory which, in their view, threatened public panic and the sales of aerosols. On the latter point they were right: By late fall of 1974 the controversy would be blamed for dropping the sales of CFC–propelled aerosols by 7 percent. The war was on, and Rowland-Molina-Cicerone-Stolarski-Wofsy-McElroy and anyone else who had the un-American temerity to suggest CFC's might be dangerous to mankind were clearly the enemy.

While the University of California at Irvine stood resolutely behind Sherry Rowland and Mario Molina and never wavered, at the University of Michigan, Ralph Cicerone began feeling the heat of official discontent from his academic superiors, while on the far side of the issue, a wide range of environmentalists from the rather sedate Sierra Club to more wild-eyed and less responsible versions rose almost as a single body to get behind the Rowland-Molina theory and couple it to the broader goals of cleaner air and water. To the environmentalists, the fact that CFC's were used in spray cans full of noncritical convenience items provided a marvelous opportunity to attack the conscience of the American consumer right in his own bathroom (which on average contained at least three cans of ozone-killing aerosol products).[26] The oversimplified cry that Americans were trading the ozone layer for such unnecessary, frivolous uses of CFC's as aerosol deodorants and hair sprays was an effective argument in many ways, but it instantly obscured two major facts about chlorofluorocarbons: Although two thirds of American usage was through spray cans, CFC's were also used in the United States as refrigerants, and as foam-blowing agents (and to a minor extent as electronics solvents); and that any truly effective steps to protect the world's ozone layer would have to be on an *international* level, since the atmosphere above the United States was not walled off from the rest of the planet. Within months, however, the prime target in the public's collective mind had become spray cans and their CFC–propelled contents.[27]

The industry had only begun to fight. Even as Sherry Rowland and Mario Molina began to breathe a sigh of relief that there was a serious show of support from other respected sc entists, buttressed by environmental outcries and increasing publicity, a multimillion-dollar counterattack got under way in the form of rapidly funded research projects designed to disprove the Rowland-Molina theory.

Du Pont, the company with the most to lose, led the attack, setting up truth squads of company spokesmen to refute the Rowland-Molina theory wherever it raised its ugly head—including scientific conferences. The theme was simple and somewhat compelling: American businesses generated over eight billion dollars of revenue from the manufacture and sale of CFC's and related products (such as the spray cans themselves), and the Rowland-Molina theory was merely a purist hypothesis that as yet had no empirical proof to back it up. Since the theory could be wrong, where was the logic in wrecking such a profitable industry employing so many Americans? More research, went their battle cry, is required before we damage such an industry.

But, came a quieter retort, what if *you're* wrong, and Rowland and Molina are right? Can we afford to wait for more proof and gamble with Earth's welfare?

And, of course, an even quieter corollary was raised: Should *any* scientific matter involving potential environmental harm of significant magnitude be decided by reference to the economics and profits involved?

Neither Sherry Rowland nor Mario Molina had ever sat down and discussed the question of just how far they should go in presenting their case to their scientific brethren, the politicians, or the press. It was simply assumed between them that they would do whatever was necessary to get the word out.

Neither of them had ever appeared before a congressional hearing, but both Rowland and Molina got their first opportunity before the end of the year. On December 11, 1974, accompanied by Ralph Cicerone, they testified before the House Subcommittee on Public Health and the Environment, explaining both the scientific case, and the reality that it was really up to policymakers to make a rational judgment based on what they already had before them. There was, Rowland told them, sufficient scientific evidence to justify at least *some* national action to limit, cap, or reverse the rapid growth in CFC production. After all, as their paper had shown, even an immediate worldwide halt to all CFC production would not solve the problem, because millions of tons had already been turned loose in the lower atmosphere. If CFC–borne chlorine really could harm the ozone layer, what had already been released into the Troposphere would keep the process going for at least a half century. Permitting industry to add to the problem while waiting for scientific confirmation was very dangerous, he told them, because of a simple and frightening delayed-reaction reality: By the time enough of the CFC's rose to the Stratosphere, broke down, and released enough free chlorine to cause a measurable decrease in the Earth's total volume of ozone, it would be far too late to prevent the effects from continuing for fifty to one hundred years. Our grandchildren, in other words, would live through the worst of *what had already been done!*

In the same hearing, Du Pont's Freon division manager, Raymond McCarthy, disregarded the essence of the warning Sherry Rowland was trying to deliver and told the panel that there was no reason for regulations until the theory had been proven. In his, and other witnesses' estimation, there *would* be sufficient time to stop dumping CFC's into the atmosphere if the Rowland-Molina theory were really correct. The fact that the beneficial effects of stopping CFC pollution would be roughly forty to fifty years in coming had been lost on almost everyone.

The Rowland-Molina theory, in the eyes of industry, was speculative and unproven, but Ray McCarthy did add that if it was ever proven that chlorofluorocarbons were a threat to ozone, Du Pont would stop making Freon. That promise, repeated later by the president of the company, would come back to haunt Du Pont.

Sherry Rowland flew back to California leaving behind him the beginnings of a major battle of conflicting claims and opinions that were already leaving policymakers in confusion. Any layman who had listened to the testimony at the hearing would have come away unsure what to believe, and that inherent confusion was going to get far worse much faster than anyone suspected.

The few lawmakers who had already entered the controversy were indeed feeling confused. Here they were being advised by trustworthy and sober scientists on one hand to take immediate action to protect the ozone layer based on a set of findings—a theory—that had not been disproven, yet a theory that others derided as premature or worse. In the same hearing they would be told that the Rowland-Molina hypothesis was either correct, compelling, and urgent, or unproven, speculative, and highly suspect. There was no way for the average congressman, senator, or staff member to have any earthly idea which conclusion was the correct one. And, overriding any environmental-protective instinct was the dark warning that premature legislation could throw hundreds of thousands of American voters and constituents out of work, all on the basis of a theory that could be proven wrong at any time. What was worse, the scientists themselves couldn't seem to agree even when they were trying to support one another's position! As one deeply concerned staff member put it, "I'm waiting for these scientists to get their act together and make a clear decision. Is the sky falling or isn't it? If *they* don't know, how the hell can *we* know? I mean, even Chicken Little and Henny Penny had clear and certain opinions. These guys keep changing theirs."

But that was the crux of the dilemma, because the CFC–ozone issue ignited by Sherry Rowland and Mario Molina was not unique in presenting policymakers with rampant, scientific uncertainty. The consistent lesson is not that scientists have difficulty agreeing and being certain, because that will always be the case. The lesson is that the policymakers have difficulty understanding the timing: There comes a point where a value-judgment-based policy decision has to be made based on the best data available at that moment, regardless of continued scientific arguments. The greater the potential risk to society, the quicker that decision point must be reached. The scientific community can tell all they know and even recommend what actions might help, but only the policymakers themselves hold the key. Throwing that responsibility back in the face of the scientific community is a dangerous avoidance of responsibility.

The year 1975 dawned on exactly that dilemma in Washington, D.C.

If the scientific community seems to be having trouble coming to a scientific conclusion, one tried-and-true solution is to appoint a board full of other scientists and force *them* to pass judgment. Even if that fails, it gets the monkey off the back of the politicians for a while, and allows them to avoid making what might be a controversial decision. In early 1975 the Ford administration used that very methodology when the president appointed the Committee on the Inadvertent Modification of the Atmosphere (IMOS). Of course, formation of IMOS did prove that the White House was aware of the problem and actively doing something, but that was little comfort to scientists such as Rowland, Molina, and Cicerone, who felt the severity of the threat to the ozone layer was so grave, the mere *possibility* their theories were right would justify a ban on at least nonessential uses of CFC's. What was needed was a value-judgment-based policy decision, but creation of IMOS threatened to throw the issue right back in the scientific arena as a "science court" test of the Rowland-Molina theory.[28]

IMOS decided in June 1975 that restrictions might indeed be necessary (a value-based policy decision), but first someone would have to decide whether chlorofluorocarbons were, in fact, a hazard to the ozone layer (a scientific decision). The initial verdict, in other words, was that the scientific community—and in particular the Rowland-Molina theory—must face a science test of sorts, and for that role, IMOS tapped the federally chartered National Academy of Sciences (NAS) on the shoulder and dumped the entire mess in their laps. If *they* determined that the Rowland-Molina theory was valid, said IMOS, then the government *should* act to restrict the production and sale of CFC's. At NAS, the assignment was about as welcome as a wet and muddy dog in a spotless living room.

The prestigious NAS tries hard to maintain as much balance and independence as possible, keeping the greatest possible distance from political maelstroms. Suddenly, however, it was in the midst of a political tornado, which was not a comfortable feeling. Anything they did might be wrong and hazardous to their reputation and the structure of governmental support.

The first NAS response, quite logically, was to stall for time. Five months passed before the first committee was even named to tackle the problem, and over a year would pass before the members finally gritted their teeth and announced something loosely resembling a conclusion. Considering their previous involvement with ozone, the discomfort was understandable.

NAS had not compiled the most trustworthy record when it came to being the supreme court of American science, and Dr. Harold Johnston of Berkeley in particular was not likely to forget the savaging both he and the Academy had taken at each other's hands in 1971. The NAS had stood behind a rather poorly supported earlier conclusion that SST's would have no effect on the ozone, and when Harold Johnston spoke out on the other side of the issue, his findings and views were treated with skepticism bordering on contempt. NAS members tended to regard Johnston as an overly emotional advocate, and he had come to regard them as gullible, ill-informed putty in the hands of the political considerations of the sitting administration.

In the Rowland-Molina crisis, however, NAS finally named a twelve-person scientific panel and divided it into two subgroups, one to rule on the validity of the Rowland-Molina hypothesis, the other to tell government what should be done about it. While Sherry Rowland, Ralph Cicerone, and Mario Molina were all fairly confident of the balance and fairness of the panel and the process, they all knew the deliberations would be made in anything but a vacuum. The chemical industry in general, and the CFC producers in particular, had plenty of friends in high places, lobbyists, and resources, and they sure as hell weren't going to let the NAS decision-making process proceed without their input, especially since legislation had been introduced in both the House and Senate that would amend the Clean Air Act and ban CFC's in one degree or another *if* the NAS panel found them hazardous. Whether the Academy wanted it that way or not, they had in effect been appointed a supreme court of science, though to extremists on both sides there was fear that what IMOS had in fact created was a star chamber.

While the NAS process got under way, various hearings and staff meetings on Capitol Hill proceeded as well, belying the fact that almost none of the staff members working for the various lawmakers were scientifically trained or knowledgeable in the area of chemistry or atmospherics. With industry snorting about this "unproven theory" and painting dire pictures of hundreds of thousands of chemical workers and their families put out of work, it seemed the CFC producers were pulling together, which meant there was a desperate need for a united front on the Rowland-Molina side of the equation. Other than the accord among Sherry Rowland, Mario Molina, Ralph Cicerone, and a few others, however, it was business as usual at the OK Corral of science, with competition, backbiting, second-guessing, and opportunism ruling all too often. Lawmakers would listen to a familiar drumbeat of caution against hasty action in the face of an unproven theory that had no empirical support, and then an array of chemists and other scientists would march across the dais emphasizing different reactions and discussing different predictions, some higher, some lower, and some not even affecting the same debate! The nitpicking disagreements simply took what was already a perplexing issue for the layman and made it impossibly confusing.

"Exactly what the hell *are* they saying? Are we losing ozone or aren't we?"

Even Mike McElroy of Harvard, who had originally followed Steve Wofsy in early support of Rowland and Molina, watered down his position to such a degree that his testimony in one hearing served to directly damage the credibility of any ozone-chlorine-CFC connection, especially Sherry Rowland's.

And over and over, the fact that there were no direct atmospheric measurements of ozone loss flew in the face of the chilling reality that no actual ozone loss might be measurable for quite a few years, but if CFC production wasn't stopped, by the time a loss was seen it would be too late to prevent a catastrophe. Mario Molina knew it. Sherry Rowland knew it. But that point kept getting lost in the static of competing nitpicking and scientific fine tuning.

Despite the intimidating appearance, the industry was not a united front, and on at least one occasion Du Pont specifically disassociated itself from some of the more hysterical industry-funded attacks on the Rowland-Molina theory. In mid-1975 the CFC producers were stunned when the fifth largest producers of CFC–powered aerosols, Johnson's Wax, announced they were ending production of CFC–filled products. It seemed a dark betrayal, yet the ranks of those who saw the impending regulations coming and decided to switch rather than fight would begin to grow in the following year.

Rowland and Molina were spending more and more of their lives in hotels and hearing rooms, and CFC's were still being produced at significant rates (though sales of aerosols were dropping rapidly). Over two years had passed since the "midnight discovery," yet the fight showed no signs of ending, and they were forever, it seemed, defending their theory and trying to get people to understand what it meant at the federal level.

At the grass roots level, though, things had begun to happen more rapidly, and movement toward legislation to ban CFC aerosols began in several state legislatures, including that of the state of Oregon. Though some chemical industry spokesmen derided the efforts as "stupid" and "essentially silly" ("What're they going to do, put a plastic dome over their state?"), industry "truth squads" burned up considerable sums of industry money in attending every state legislative hearing (and even one city council hearing) to counter the Rowland-Molina theory.

Oregon, however, fell first, banning CFC aerosols in June 1975 and providing a stiff penalty for selling such ozone-destroying products. The governor of Oregon, in signing it, acknowledged that the action was based on unproven theory, but that it was wiser to "err on the side of caution."

In Washington, D.C. the months continued to tick by as the NAS panel agonized over its task. Sherry Rowland was getting genuinely frustrated with the wait, however, and all the more so when he heard that the Department of Commerce had already come out against CFC regulations even before the NAS report was finished. Equally worrisome was a statement by the Environmental Protection Agency's chief calling for an international solution. Certainly worldwide CFC regulation was vital, but for the EPA to call for it at that moment would give the industry a new rallying point: Why should we act unilaterally? No federal CFC regulations until the rest of the world joins us in a treaty!

No matter who was doing the arguing, the heart of literally every debate concerning CFC's held exactly the same key question: Was the Rowland-Molina theory right or wrong, true or false, operative or inoperative? In the middle of the maelstrom of scientific, industry, political, media, and public charges, countercharges, claims, outcries, apathy, and scary predictions stood the same two affable, highly intelligent, quiet and conservative chemists. Somehow, Sherry Rowland was keeping himself calm, and Mario Molina was spending as much time as possible in research, but if the winds blew gently around them, it was only because they stood in the eye of the hurricane. It was not the safest of all possible positions to occupy.

By midsummer of 1975 researchers at the National Center for Atmospheric Research (NCAR) and the National Oceanic and Atmospheric Administration (NOAA), both in Boulder, Colorado, had become fully involved in helping NAS make their decision by searching for actual, measurable readings that could shed some light on "the Theory." Three steps were considered necessary to prove the Rowland-Molina findings. The first was to show that CFC's were actually reaching the Stratosphere in their original molecular shape, and the second was proving that ultraviolet light breaks up the CFC molecules into their various components, releasing chlorine or reactive chlorine compounds (such as chlorine oxide). Both had been accomplished by early fall. The last step—and perhaps the most important—was the search for the chemical "smoking gun": ClO, or chlorine monoxide. There could be no ClO in the Stratosphere unless it was the by-product of ozone destruction. If ClO wasn't there, Rowland-Molina were wrong.

Out in east Texas working with a limited budget in a far corner of atmospheric science at a NAS facility called the National Scientific Balloon Facility, another tall, congenial scientist named Jim Anderson was busy trying to answer question number three with eight-hundred-foot-long balloons made of thin polyethylene film and carrying huge packages of sensitive instruments to altitudes of 150,000 feet. Anderson, a University of Michigan research associate, who with his prematurely white hair and broad, craggy face resembles actor Peter Graves, in effect had before him a scientific version of an impossible mission: finding evidence of a particular molecule scattered in the atmosphere at concentrations of no more than two parts in a billion.

Before Jim Anderson found the smoking gun, however, the Rowland-Molina theory was nearly blown out of the sky by another sudden "midnight discovery" back in California. And the scientist who tripped over the new evidence? Mario Molina himself.

In the societal scheme of things, lawyers are never supposed to lie to judges, reveal privileged client statements, or play around with the funds clients entrust to them. Those are bedrock ethical requirements, similar to a doctor's Hippocratic oath. In science, there is a traditional ethic that scientists must never hide or understate known exceptions and limitations to their theories. Scientists are never to conceal new contradictory findings, no matter how destructive they might be to theory or reputation. Science is, after all, the search for the truth of things in the universe as we can know it, and truth, either as quality or as commodity, is always in limited supply. A very common theme stretches back through science even to the days of alchemy: Today's truth is tomorrow's disproven theorem. A scientist who discovers something new that assassinates yesterday's truth, but who fails to report it, is not a true scientist in the eyes of that calling. Thus there was no hesitation on the part of Mario Molina or Sherry Rowland in telling the National Academy of Sciences panel—which was deliberating on the veracity of their theory—that Mario had found something new in the lab that put the original estimates of eventual ozone loss in serious doubt.

Aided by Dr. John Spencer, a new chemist who had joined the team at Irvine, Mario had been checking methodically for any other molecules that might in any way become a sink for chlorine, or somehow interfere with the chlorine-ozone destructive catalytic cycle in the stratosphere. Mario had long been totally at home in the back stacks of dusty science libraries engaged in scholarly research, and it was in just such a foray that he found in some old German chemical literature some references to previously unexplored properties of a molecule he hadn't paid much attention to before: chlorine nitrate. He and Sherry Rowland had considered chlorine nitrate in 1974 as a possible sink for chlorine, but its lifetime would be too short to limit the chlorine's destructive attraction to ozone. Or so they thought.

Now, however, a series of delicate but straightforward lab experiments to validate that conclusion suggested something entirely different: The chlorine nitrate compound was much more stable than they had believed, which meant that it *could* tie up large numbers of chlorine atoms.[29] But when Mario cranked the new figures into his mathematical models, the total amount of projected global ozone loss they had originally pegged at 7 to 14 percent plunged through the floor! (In fact, in one set of calculations done elsewhere, it looked for a while as if the net result of added Stratospheric chlorine could be an ozone *gain*!) Molina and Rowland were in shock, and a bit of agony. They had to put the world on scientific red alert, perhaps for nothing.

To make matters more painful, the NAS report, which had been awaited with great trepidation by both of them for so long, was finally scheduled for release in a matter of weeks, and the new data would undoubtedly send everyone back to the lab, costing many more weeks.

Nevertheless, an immediate phone call went out to the NAS group from Sherry Rowland, reporting the results. Predictably, the NAS panel was thrown into immediate confusion, and late-night sessions began in numerous labs and computer-modeling facilities to try to find the true extent of the role of chlorine nitrate in tying up free chlorine in the Stratosphere.

Within days, other labs and chemists had refined the models to show that ozone loss would occur and would be significant, but the chlorine nitrate would to some degree become a sink for chlorine that had come originally from CFC's, lessening the overall effect on the ozone layer of the Earth. So they were right, but not quite as right as before (there certainly was no production of ozone—that finding was wrong). The entire affair could have ended there if the issue was not also an economic one, but as Sherry Rowland feared, the CFC industry pounced on the news like a duck on a June bug and ran to the press trumpeting that the Rowland-Molina theory had been disproved.

It had *not* been disproved. It *had* been ameliorated, at least for a while. It took several months and some very long hours slaving over hot computers and calculators before scientists such as Paul Crutzen working with Ralph Cicerone were able to report back to the NAS panel that the chlorine nitrate changed some aspects of the problem, but that the overall loss of ozone would still be toward the low end of the Rowland-Molina estimates of 7 to 13 percent worldwide. The flap delayed the NAS report by five months, but since the scientists who had brought forward the challenge to Rowland-Molina were none other than Rowland and Molina themselves, there was a beneficial effect: an added veneer of trustworthiness [illegible] the theory. If even the progenitors were still working on the problem and reporting honestly on a real-time basis, their neutrality was far more substantial than their opponents had wanted to believe. Now even the CFC industry grudgingly began to acknowledge behind closed doors that there was reason to believe in "the Theory" and the inevitability of CFC regulation.

On September 13, 1976, NAS released their report with the ruling that Rowland and Molina were correct. The Earth, they concluded, would in fact lose somewhere between 2 to [illegible] percent of its total ozone protection, with 7 percent being the most likely figure, if nothing was done to stem CFC production.

But the second section of the NAS panel had reached a different conclusion in effect. While it acknowledged the finding that Rowland and Molina were right, it recommended that no immediate regulation be enacted. The government, it said, should be given two more years to study the problem. The Academy, in other words, had attempted a compromise; in the end, all it had succeeded in compromising was the integrity of its effort.

Nevertheless, Sherry Rowland and Mario Molina [illegible] vindicated, and within a month the U.S. Food and Drug Administration disregarded the "wait for more research" recommendation and moved to phase out nonessential CFC use in aerosols—a beginning victory that had taken three years of hard battles and untold personal and professional tolls on both men.

Things began to happen at a faster pace, and by early 1977 many different CFC–aerosol packagers began switching to pump dispensers for household products and advertising heavily to promote the "ozone-safe" qualities of their new, non–CFC lines. Such moves, of course, were in anticipation of the inevitable, which finally occurred on May 11, 1977, when several government agencies jointly announced a timetable for mandatory phaseout for nonessential CFC aerosol products, to be effective in late 1978.[30]

The battle—the first battle—had finally been won (though only in the United States, and soon after in Canada, Norway, and Sweden). But the war, so to speak, was just beginning. There were many other uses of CFC's continuing unabated, and millions of tons of the stuff would continue to be manufactured—and released—each year all over the planet. Even aerosol spray cans continued to be produced and sold outside the United States. Yet the American tendency toward pragmatism, and the desire to say, "Okay, that's done and over with, let's get on to the next problem," began to operate, and the war was considered won. Americans have a penchant for clean solutions and heroes riding into the sunset—a "good exit," in acting terms. But while Rowland, Molina, Cicerone—and many others who were now convinced of the threat—watched in utter dismay, the audience began stampeding out of the theater, falsely secure in the "knowledge" that the ozone-killing properties of CFC's had been eradicated by the ban on spray can usage. Even the fact that only four countries had instituted such a ban failed to register on the public. As the seventies came to a close, the perception took root that the ozone war was over, that there was no more ozone problem. That perception was aided by a string of unfortunate reports over the next few years that had ozone loss estimates fluctu-

ating all over the map, from zero loss to greater than 20 pe
cent.

NAS itself was responsible for much of the confusion, i
suing well-meaning reports that in 1979 pegged project
ozone loss at a whopping 16.5 percent, but downsizing that
a 5 to 9 percent loss in a 1982 report, and a 2 to 4 percent lo
in 1984. The only consensus during those years was that th
atmosphere was a vastly more complex place chemically tha
anyone had figured, and although the basic chemistry of th
Rowland-Molina hypothesis was never questioned, the tot
global ozone loss figures simply defied precise estimatio
With the world concentrating on other things—and the ele
tion of President Ronald Reagan, to whom environment
movements were direct threats to free enterprise and th
American way—Sherry Rowland was fighting a losing batt

In May 1981, Reagan's new Environmental Protecti
Agency administrator, Anne M. Burford, testified before h
Senate confirmation hearing inquisitors that, in her opini
the CFC issue was "highly controversial." Indeed, in a bo
published long after she had been forced out of the EPA f
doing practically nothing to protect the environment, s
would reveal her true attitude toward all the scientific wo
that had gone into validating Rowland-Molina: "Rememb
she would write, "a few years back when the big news w
fluorocarbons that supposedly threatened the ozone layer?
With such attitudes and continued waffling in the scient
estimates of ozone loss, the advice Sherry Rowland was g
ting was turning toward the "abandon ship" line of reasoni
He had done enough. He was wasting his career.

Mario Molina left U.C., Irvine, in 1982 to head up a
search group at the Jet Propulsion Laboratory in Pasade
leaving Rowland still engaged in refining the ozone resea
Though he had become an assistant professor in 1975 and
longer reported to Sherry Rowland, Mario Molina contin
to collaborate with his former boss, and stayed in effec
Rowland's side throughout the years of controversy over w

had become known worldwide as the "Rowland-Molina theory." Rowland, however, had taken most of the heat. Being more comfortable in the spotlight of public scrutiny than Molina, Rowland had become the visible element of the team, and the fallout from that exposure was taking its toll. No longer considered a "balanced, neutral" scientist, Rowland received no invitations to speak at chemical industry functions, and very seldom was invited to speak at other university chemistry departments. Such an institutional snub would have been very puzzling for a senior chemist of his stature—except for his advocacy of "the Theory." There was a penalty to be extracted for those who, regardless of motivation, care, responsibility, or correctness, have the unmitigated temerity to take science into the arena of policy or (shudder) policy recommendations. While Ralph Cicerone felt only minor setbacks in his career and Mario Molina even less, Sherry Rowland's professional horizons without question were affected. It was a form of negative feedback that his students—and many others in graduate and postgraduate programs—saw and took to heart. Here is what happens when you become "controversial." Take heed, young scientist, and keep your mouth shut.

Dr. Susan Solomon, a former doctoral student of Harold Johnston at Berkeley who had joined NOAA at Boulder, knew Sherry Rowland and held him in the highest esteem personally and professionally, but in a meeting in 1983 she advised the senior chemist to give it up: "The projected ozone losses are too uncertain and low—in the noise level. You're wasting your time, Sherry."

It was a warning she was to remember acutely later, in the spring of 1985, when a certain incendiary scientific paper landed on her desk for review.