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Rayon Will Be with Us

Viscose was a pacesetter at the start of the twentieth century, the first major synthetic-fiber success story. In the 1920s and 1930s, rayon led the way as the prototype of a multinational business enterprise, an early model of what would become the dominant modus operandi for large business entities after World War II. Then in the 1970s, just as the updated term "transnational" began to come into vogue, viscose once again was at the forefront of a new business trend. Spin-offs, shutdowns, and offshoring became standard operating practice in the rayon industry for the remainder of the twentieth century.

The prelude to this dismantling was a series of mergers and acquisitions that left the old viscose principals unrecognizable by name. More than that, many of them no longer manufactured rayon as their main product. The first to be transformed through corporate mergers were some of the major U.S. viscose manufacturers. In 1963, FMC (originally the Food Machinery Corporation) acquired the American Viscose Corporation, which formed the basis of a new fibers group operating within its larger conglomerated enterprises. An entity called the Midland-Ross Corporation had taken over the Industrial Rayon Corporation in 1961; the old Elizabethton rayon enterprise had morphed into Beaunit, and in 1967 it was taken over by the El Paso Natural Gas Company, becoming part of another "diversified" portfolio.[1]

European rayon followed suit. In 1968, SNIA merged with another Italian manufacturing group, BPD, and got into the chemical business and the defense industry. In that same year, Hoechst acquired what had originally been Süddeutsche Zellwolle; in 1969, the Dutch-German integrated ENKA-Vereinigte Glanzstoff (AKU since 1929) merged with a paint and chemical manufacturer to become Akzo.[2]

A cycle of plant shutdowns led off the 1970s. It set a pattern for reshufflings and closures that continued unabated for the remainder of the century. Enka as Akzo led the way, announcing in 1972 its intention to close multiple production sites. The viscose workers in the Netherlands did not go along with this plan, occupying Enka's rayon plant at Breda in a Dutch trade union first. This protest caused Akzo to back off its scheme, at least for a time.[3] The workers' anxieties during the uneasy truce that followed are captured in a photo-documentary series of the time, "Unemployment in the Netherlands." It includes an image of a lone worker sitting on a stool facing a row of autonomously operating machines in an Enka plant, juxtaposed with newspaper text discussing workers' fears of impending layoffs.[4] After a decent interval, Akzo did shut down the Breda plants, and this time even a hunger strike by workers did not stop it. Then, in a further step to get out of the cellulose fiber business altogether, Akzo sold off their remaining American Enka subsidiaries to the chemical giant BASF. In 1989, Akzo celebrated its twentieth anniversary by giving its remaining employees logo-branded sports jackets. Five years later Akzo merged with Nobel, the Swedish chemical conglomerate, to assume yet another new corporate identity as AkzoNobel.[5]

Dutch workers had been able to temporarily delay the inevitable, but there was not even a brief respite for the employees of Courtaulds. The blow fell first and hardest at Flint, in Wales, where there was the greatest concentration of Courtaulds viscose workers. In late October 1976, Courtaulds gave notice that its Castle works would close a few weeks after the New Year. It was abundantly clear that Courtaulds was likely over the coming years to eliminate its remaining operations in the area as well. Near midnight on 2 May 1985, with closure of the Greenfield plant announced and the axe about to fall on the Deeside mill too, MP Keith Raffan stood up in Parliament to deliver an impassioned plea for his "blitzed local economy," warning that Courtaulds was not only making its workers redundant but also was likely to walk away and leave behind a "burning toxic tip" (dump), as it had done at the Castle works.[6] As with MP Kelly's parliamentary speeches of more than half a century before, Raffan's words came to naught.

Today, nearly nothing physical remains of what had once been the bustling rayon factories of Flint. All the main buildings have been pulled down: there

is virtually no way to know where anything stood unless you are guided by locals who remember what used to be there. There is a retail shopping strip where the Deeside factory had been, and "business parks" for small-scale enterprises at the other sites.

In 2011, I was lucky enough to be taken around Flint by Ken and Brian Davies, who had grown up in the area. Their father, Robert, had started work at the Greenfield Courtaulds facility in 1937. Except for five years of RAF service during World War II, until late 1956 he was a rayon process worker, including time in the churn room. He went on to another job for a couple years and then had his first heart attack one morning in 1958. He was fifty years old. Robert Davies did not live long enough to see the plant closings that were to come—he survived the heart attack, but later experienced a series of disabling strokes, succumbing to his illness in 1968, age fifty-nine.[7]

Later in the same year as my visit to Flint, I arrived on a warm fall day in Wittenberge Elbe. I wanted to see what had become of the VEB Zellstoff- und Zellwollewerke Wittenberge, the postwar rebirth of Phrix in the former East Germany. In 2001, fifteen years after the shutdowns began in Flint, but even more abruptly, the factory was shuttered, along with almost all the rest of the manufacturing of the once-thriving industrial city. Wittenberge Elbe became something of a poster child for postunification economic blight.[8] Unlike what I saw Flint, though, many of the original Phrix factory buildings from 1938 were still standing, and most were being repurposed, including one that housed the Alten Zellwolle restaurant and caterer.

I was shown around by a former Zellstoff- und Zellwollewerke worker named Helmut Worbs, along with a local historian and retired schoolteacher, Günter Rodegast. On a green lawn near the old administration building, a group of former workers had established an outdoor museum of selected equipment and parts from the defunct factory. Its centerpiece was a large metal viscose churn, looking like a cross between a cement mixer and a deformed, bulbous cannon. As we walked in the open space between the remaining buildings and the banks of the Elbe, the historian speculated on where the barracks of wartime slave laborers may have stood, no marker of them remaining. There is a de facto memorial to those times that, in its way, is nonetheless moving. Near the center of the factory grounds, a small manmade pond surrounded by trees is graced by a statue that clearly dates from original Phrix establishment: a nude athlete cast in metal, standing on a pedestal. One can only surmise that at the time of the plant's founding, it was intended to embody the nobility of modern industrial manufacturing, epitomized by rayon.

I visited one other worker-run museum memorializing a defunct rayon operation, the former Svenska Rayon located in Varmland, north of Gothenburg on the west coast of Sweden. The story of Svenska Rayon reflects the hybrid nature of the mixed economic model under which the company operated for much of its existence. The business depended on public-sector underpinning, and direct governmental aid escalated during the 1970s, when rayon was faltering in Britain but was entirely protected in East Germany. Support for Svenska Rayon was driven by a perceived national-security need under the tenuous hypothetical that Sweden might somehow be cut off from imported fibers were its sole rayon producer to go out of business.[9] When governmental support eventually was pulled out, the company continued for a while after a private takeover, but then finally succumbed in 2004.

On the day of my visit, a colleague and I first stopped by to meet with Ragnar Magnusson, a retired Svenska Rayon worker and something of a writer in residence among the retirees, having produced not only a history of the factory but several works of fiction as well. He began working in the factory in 1950, eight years after the plant first opened. Even before starting, he had heard rumors that the working conditions were bad and that some workers had collapsed on the way home from the factory. He remembered that a female physician who began researching this problem was soon transferred. Ragnar reported that eye problems were so common that there was a rule about them: you showed your eye problems at six in the morning to the guard at the door, and if you were judged unfit for work, you could go back home. If someone passed out on the job and had to be pulled out to fresh air, which happened with some frequency, the victim was given milk to drink as an antidote. Ragnar was aware that the vapors had a depressive effect and that some workers "became brooding, committed suicide or attacked the family." Although over the years conditions became better, and air levels were later measured regularly, excess exposure continued (inserting zeroes into the data points brought down the averages to within targets, Ragnar recalled).[10]

We went with Ragnar to meet some of his former workmates and to see the small museum they had created in a room made available by the local community council.[11] There were samples of some of products that had been made (both filament and staple) as well as photos and even signage from the plant, although nothing on the scale of the Wittenberge artifacts. One of my hosts was still convinced that things had been turning around economically and that the new owner had pulled the plug prematurely. Before we departed we all sat down to have cake and sing happy birthday to Ragnar, who was celebrating his eighty-eighth birthday that day. The rest of the group was not much younger.

In the years that spanned the closures in Flint and Wittenberge and Varmland, the rayon business across Europe and the United States changed radically. In a game of musical chairs, corporate owners and business plans kept changing, and each time the tune switched, another plant ceased operations and more workers were out of a job. Across its British operations, Courtaulds' textile business over those years sputtered and then failed utterly. What hadn't been shut down by 1998 was finally bought out by Enka-cum-Akzo-cum-AkzoNobel. This remnant of a once mighty synthetic textile empire was folded into AkzoNobel's newly constituted Acordis fibers group.

Ironically, the one piece of the cellulose fiber business acquired in the Acordis deal was the vestige of Courtauld's attempt to reestablish a foothold in America, its rayon staple factory in Axis, Alabama. The plant, operating since 1952, had been augmented with a new production line in 1992. The new product coming out of Alabama was meant to be Courtaulds' great cellulose hope, a novel synthetic fiber called Tencel.

Tencel began to be developed in the mid-1980s as the focus of an effort that Courtaulds remarkably designated its "Genesis project."[12] This may or may not represent a subliminal homage to "Project Genesis," central to the plot of the then-recent film *Star Trek II: The Wrath of Khan* (1982). In the movie, the Genesis device is meant to rearrange matter so that a planet with a hostile environment could be made habitable. The folks in Courtaulds' research and development department meant to rearrange cellulose with a chemical alternative to carbon disulfide in hopes of making a product niche that was economically habitable. The substance at the heart of Courtaulds' Genesis project was capable of putting cellulose into solution, just as carbon disulfide did, but with an entirely different chemical structure: N-methyl morpholine-n-oxide, or NMMO for short.

Courtaulds had been innovating with NMMO for a while, but not at Axis, where for decades it was business as usual: making viscose with carbon disulfide. By the time of the plant's purchase by AkzoNobel in 1998, it had undergone close to twenty years of governmental occupational and safety health investigations. The National Institute for Occupational Safety and Health carried out it first preliminary walk-through at Axis in 1975 and then did a larger study in 1979. Air sampling documented peak values of carbon disulfide that were ten times as large as the OSHA standard (a standard that, even if met, NIOSH had determined was not sufficiently protective of human health). NIOSH did not recommend any specific intervention, temporizing instead with a call for further study of the question.[13]

In 1996, two years before the Axis factory passed into AkzoNobel's hands, Alabama's Department of Public Health reached out to NIOSH for a follow-up,

asking for its help in addressing illness among the Courtaulds employees. At nearly the same time, an employee from the factory activated NIOSH's "Health Hazard Evaluation" system by formally requesting governmental action. The next month, NIOSH dispatched a physician and an industrial hygienist to Alabama. The team called in at the plant, made a brief assessment, and suggested, once again, further study. More than a year passed. Finally, NIOSH submitted to officials at Courtaulds an outline of its proposed study.[14]

Even though the process was moving along slowly, it was not necessarily out of line with Health Hazard Evaluation protocols. What followed next, however, was quite remarkable. Courtaulds fired back a negative response to NIOSH's proposal, adding to its own lengthy cover letter an additional twenty-seven pages of supplemental comments solicited from five contracted consultants. At first, NIOSH backed off. As part of its response to the critique from Courtaulds, NIOSH stated that its survey would be delayed because the physician originally assigned to the project was no longer with the agency.[15] By the end of 1997, NIOSH capitulated completely: there would be no study. NIOSH claimed that the workers knew too much about the hazards of carbon disulfide, thus tainting any possible results from a questionnaire survey. NIOSH did not state how such foreknowledge would change carbon disulfide air measurements or physical health defects objectively documented.[16]

Although all this transpired before the AkzoNobel takeover, the future owners were aware of NIOSH's interest in the Axis facility. Even before buying the plant, AkzoNobel had cosponsored, along with Courtaulds and other members of the Carbon Disulfide Panel of Chemical Manufacturers Association, a critique of NIOSH's exposure data from its original study at the plant in 1979. The panel's hired consultants reached the convenient conclusion it was not carbon disulfide, but rather a carbon disulfide–racial interaction, that explained any effects that had been seen.[17]

As part of its due diligence, AkzoNobel should have been cognizant of any legal liabilities that it was assuming by taking over the Axis operation. For one thing, there was a major personal injury suit winding its way through the courts. The medical details of the case had been published in the high-profile medical journal of the National Institute of Environmental Health Sciences, *Environmental Health Perspectives*.[18] This scientific paper documented the downhill course of a rayon worker who suffered from devastating neurological disease, from his first medical assessment at age sixty-two until his death seven years later. This man had spent more than two decades as a viscose rayon worker, much of it in the spinning room. Although the author of the paper discreetly does not name the employer, a follow-up letter to the editor of the journal cited the legal decision, which in the end had gone against

the worker, a man named West Berry Becton. The carbon disulfide he was exposed to was purchased from a chemical company, which was the target of the suit. The factory that employed Becton, alluded to in the proceedings but not at direct legal risk, was none other than Courtaulds.[19]

Courtaulds was in this relatively protected position because workers' compensation statutes across the United States provide insulation from liability exposure: it is an insurance scheme that effectively precludes employees from suing their employers. A fixed schedule of benefits reigns in any potential award in the case of damages, and pain and suffering are not accounted for. Of particular importance, however, an employee is free to sue a "third party" outside the constraints of workers' compensation, for example, the supplier of a toxic substance (the seller of the carbon disulfide) that purportedly led to an illness. This was exactly what proved to be Johns Manville's asbestos Achilles' heel, since it was the product supplier, but not the employer, of most of those injured by the fiber.

It is a different matter entirely when it comes to the general public. Since carbon disulfide is not retained in rayon or cellophane by the time these products are sold as finished goods, consumer product liability has never been of particular concern to the viscose industry. Not so with environmental contamination. Two Alabama residents who lived adjacent to the Axis factory brought this message home to the corporation.

When Rosie's health began to decline in 1991, those treating her could not determine the cause. She was referred to a university center for further evaluation. While there, she improved, only to deteriorate when she went back home. In 1993, a similar condition began taking its toll another local resident, Whisper. Blood tests taken from Rosie and Whisper as well as from other horses on Horace and Margaret Long's farm confirmed the presence of either carbon disulfide or its chemical breakdown product.[20]

In the court case that ensued, an Environmental Protection Agency's Toxic Release Inventory Fact Sheet for Alabama was put into evidence. It revealed that in 1991, Courtaulds released 42,454,520 pounds of carbon disulfide into the air around Axis, discharged 43,105 pounds of carbon disulfide into the "surface water," and disposed of 430,000 pounds carbon disulfide into land. Remarkably, this pollution was not trending down over time, but actually had increased by nearly 50 percent from previous levels in the mid-1980s.

The Longs were initially awarded a judgment of one million dollars against Courtaulds, recompense for the lost value of their land and the huge veterinary bills that they had amassed. Even with the workers' compensation firewall, the environmental vulnerability was obvious. The surest solution would have been to recapture more of the carbon disulfide, thus controlling emissions. But that

was an expensive prospect. The rayon baths continued to spin, as did corporate management. Nearly as soon as AkzoNobel took over and rebranded the operation as Acordis, even before the end of 1998, it was already touting a newfound commitment to clean living, the documentation for which was a brochure for community distribution. In a presentation to the EPA, Akzo proclaimed: "As part of its corporate culture, Acordis believes in taking leadership positions, including its positions on the environment. The Acordis facility in Mobile was the first local company to provide environmental brochures to the community, in which the company made commitments to future performance."[21]

There was insufficient time to establish whether substantive environmental actions would have followed. The following year, AkzoNobel decided to get out of the business, divesting Acordis to an entity called CVC Capital Partners. (This entity was the venture capital arm of Citicorp.) In the interim, Courtaulds had appealed its unfavorable horse-poisoning verdict. In September 2000, the Alabama State Supreme Court voided the award and ordered a new trial on technical grounds: the jury decided the case on the basis of a nuisance claim that should have been disallowed, because the factory's carbon disulfide pollution was already ongoing at the time the Longs moved onto their farm.[22]

Meanwhile, CVC was seeking to expand its fibers business, attempting in 2001 to purchase the still-independent and functioning rayon business at Lenzing in Austria. When the European Union forbade the sale, CVC reversed course, breaking up Acordis for good in 2004 and selling its Alabama facility to Lenzing. The sale gave the Austrians access to the U.S. Tencel unit as well as to Courtaulds' pilot operation for the fiber (now controlled by Acordis) in Grimsby, England. (Acordis had shut down standard viscose production there in 2001.)

Lenzing Fibers, as it turns out, was something of a standout success story during the overall decline in the European and American viscose business.[23] In fact, it was the last survivor when it came to rayon in the United States. In 1992 Lenzing had acquired the rayon staple operation in Lowland, Tennessee, that BASF had taken off Enka's hands but no longer wanted.[24] American Enka had begun construction of the factory on the banks of the Nolichucky River back in 1944. This was at the height of the war boom in rayon, at a time when Enka's parent company was under Nazi occupation in Holland, BASF was a linchpin in the I. G. Farben combine, and Lenzing was the jewel in the crown of the Thüringischen Zellwolle group.

For a while, Lenzing made a good run of it at Lowland, but in the end it had no more a long-term interest in a stake in Tennessee rayon staple than

had BASF or Enka. In 2002, Lenzing transferred ownership; the operation briefly emerged as Liberty Fibers before going under for good in 2005. Remnants of the classic 1940s design of the long-since-abandoned facility are still evident, in particular its sawtooth-clerestory roofline, standing alone as if dropped into Hamblen County in upper East Tennessee and then forgotten.[25]

Even though Lenzing eliminated the last vestiges of U.S. rayon staple, in Austria it continued with traditional viscose production and expanded further into Tencel manufacturing (under the product label Lyocell). I visited Lenzing in September 2012. On the way in from Vienna, just before coming to Lenzing the road passes by through the nearby village of Pettighofen, where the factory's subcamp of Mauthausen had been sited. I arrived a bit early for my appointment, so I stopped in to get a bite at the restaurant-café Amigos situated just outside the factory gates, contemplating over lunch what I might see at the factory. The year before, in a North London assisted-living community, I had met with a survivor of the women's camp at Pettighofen. She too had been to see the modern Lenzing operation as an invited guest of a company sensitive to its wartime record. She remembered little of the visit that she could compare to from her months as a slave laborer, emphasizing the impressive scale of the modern Lenzing operation.

The factory is indeed quite impressive. Up-to-date equipment facilitates all the traditional steps in viscose rayon production, from handling pulp to mixing and aging the viscose solution to spinning out the filament and then, for staple, gathering it into a tow and slicing the rayon into short fibers that are baled like cotton. Key at Lenzing are a system of modern enclosures and a ventilation system that combine to form an effective barrier between the workers and carbon disulfide. A sleek medical department staffed by occupational health specialists closely monitors urine samples for any indication of excess absorption of carbon disulfide by the employees.

Yet some things have not changed that much over time. The tallest building in the complex is a multistory tower for material handling that dates from Lenzing's original construction just before World War II. I climbed the tower with my tour guide, a former plant operative whose current duties include public relations. He proudly noted that their last suicide from that spot had occurred in the 1950s, which I took to mean suicide due to mental disturbance from carbon disulfide toxicity, given its causal association with derangement leading to suicide, well known since the nineteenth century. One other architectural feature struck me. Just as at Wittenberge, to the side of one of the old building were a small pond and, beside it, what was left of a small figurative statue in the classical style.

The American Viscose Company added to its glory a cellophane crown when it merged with Sylvania. FMC took over both parts of the business in 1963. One of the major rayon facilities it acquired was in Parkersburg, West Virginia, but when that plant stopped being lucrative, there was no reason to keep it going. One of the former workers there, a man named Roger Mackey, who now runs an antique and clock-repair shop in Parkersburg, described his work and the abrupt plant closure in these words: "I worked in the churn room for a while when I first got hired, they had a Fluid they mixed with crumbs they called CS2—It was some bad stuff. Someone said that if a tank they kept it in ever exploded it would blow up the biggest part of Parkersburg. I do not know if that is true but that is what they were saying. The old FMC plant I worked at closed down November the 14th 1974, the 15th they had they gates locked and was handing out checks through the fence."[26]

Not long after, in 1977, FMC sold off the rest of its rayon to a newly established entity, Avtex Fibers, Inc. It didn't take long for Avtex to shut down the former AVC rayon staple plant in Nitro, West Virginia. That closure came five years after NIOSH had visited the facility. Its report at the time was damning: seven out of eight of workers who cut the stable were exposed to carbon disulfide in excess of OSHA's weak standard; remarkably, brief exposures to levels even one hundred times as high as that were documented.[27] This extreme overexposure took its toll. In *Muscle and Blood,* her book from 1974, the investigative reporter Rachel Scott told the stories of some of the rayon staple cutters at Nitro who were made ill. One was a man named Ronald Sayre. Soon after he started work at Nitro in 1969, he began to experience psychiatric symptoms: "I couldn't sleep. It was making me think weird things. I thought everybody was watching me. I remember one night, I punched out at ten o'clock, and I thought my father was outside, in the swamp, waiting for me. I went out and looked for him. He wasn't there."[28]

He was hospitalized not long after; three other workers were institutionalized at the same time with similar complaints. The company did not acknowledge that Sayre's psychotic break was due to carbon disulfide: his workers' compensation claim was denied.

After dispensing with Nitro, Avtex tried to keep going what had once been the flagship factory of American Viscose at Front Royal, Virginia. After a protracted, five-year fight with federal and state regulators over its record of pollution at the site, Avtex found a solution to that nagging problem as well: it declared bankruptcy.[29] The Avtex Fibers name has continued on, however, as the Avtex Fibers Superfund site at Front Royal, which includes carbon disulfide among a long list of contaminants. As the EPA describes it:

> The contamination discovered at the Avtex Fibers site was of such magnitude and complexity that the area has been the subject of a number of removal, enforcement, and long-term cleanup actions. Tons of rayon manufacturing wastes and by-products, zinc hydroxide sludge, and fly ash and boiler room solids were disposed of on site in 23 impoundments and fill areas encompassing 220 acres. Waste disposal practices at the plant contaminated the groundwater under the site and in residential wells across the river from the site. . . . When the plant closed in 1989, the community was left to contend with severely contaminated land and water, the devastation of its manufacturing heritage, and the loss of approximately 1,000 jobs.[30]

In its transactions with Avtex, FMC retained its cellophane business, the Sylvania crown passed down from AVC, or what was soon to be left of it. Six months after the Avtex deal, at the beginning of 1977, FMC announced that it was shutting down cellophane production at Marcus Hook, Pennsylvania, where AVC first had started in rayon.[31] At the same time, FMC committed to expanding production at its remaining factory, in Fredericksburg, Virginia. A year and a month passed before FMC announced it was calling it quits at Fredericksburg too.[32]

FMC was not alone in the U.S. cellophane business. At the start of the 1950s, the Olin Corporation had made its foray into the sector, building off experience in the cellulose trade it had gained through munitions manufacturing. Olin's foothold in cellophane was its facility on the edge of the Pisgah National Forest near Brevard in Transylvania County, North Carolina. It was on the second floor of the Film Division, where the industrial equipment (called a barette in the trade) that churned the mix of cellulose and carbon disulfide was located, that the highest exposures to carbon disulfide occurred. Well into the 1970s, this was an ongoing problem. An Olin employee named Marvin Gaddy described the working conditions there: "Sometimes when we'd open those barettes, you get enough fumes to just about knock you out. We'd then take our scrapers and scrape out all that was stuck and there'd still be a lot of CS_2 in it. The company had given us testing machines to measure the fumes, but they would only go up to 50 parts per million."[33]

Another worker from the second floor, George Sanders, likely had even higher exposures. "He used to empty all these trash cans full of CS_2. Boy did he get a lot of fumes!" recalled a workmate. "I worked around him the week before he died and you could definitely tell that he was in a strain. He was awful bad depressed. He wouldn't say nothing to no one. His wife was pregnant at the time. He died of a shot gun wound one Saturday night. Everybody said it was just an accident."[34]

A team from NIOSH went to North Carolina to interview Olin's workers in 1973, but its conclusions were equivocal at best: "There is no doubt that occasional acute exposures to CS_2 have occurred episodically and that these exposures have provoked the expected medical symptoms. These exposures have not been frequent. There does not appear to be sufficient medical evidence at this time to warrant a conclusion that chronic exposure is occurring in a sufficient degree to provoke illness."[35]

The ten-page NIOSH report makes no mention of any suicides or "accidental" deaths such that of George Sanders. Olin shut down its operation in 2002. Not long after, the EPA became involved because of concerns about environmental contamination. The concern was not misplaced. In 2008, a redevelopment company purchased the Olin property, and in May of that year a half-mile-long fish kill in the adjoining river resulted from the release of old waste from the abandoned factory. All the plant buildings have since been torn down, but according to its current EPA "Superfund Profile," the site remains unused.[36]

American Viscose/FMC was always in second place in cellophane, and Olin got into the game late. It was for DuPont that cellophane traditionally had been the big moneymaker. But over time, even it abandoned the business. DuPont's cellophane exodus started as far back as 1964, when it shut down its plant in Old Hickory, Tennessee.[37] Its cellophane factory in Richmond, Virginia, came next, in 1976.[38] Then DuPont converted (and downsized) its cellophane operation in Davenport, Iowa, to one making a noncellulose shrink film. Finally, in 1986 it sold the remnant of its cellophane business, DuPont's old factory in Covington, Kentucky, and a state-of-the-art factory in Tecumseh Kansas.[39]

The assets went to an Atlanta corporation called Flexel. A decade later, Flexel went belly up. Covington was finished for good, but the Tecumseh plant was bought out of bankruptcy by a Brussels-based corporation, the UCB group, that had already gobbled up all the cellophane makers in Britain.[40] In fact, it had capped off its transparent-film buying spree with the purchase of British Cellophane, along with the rights to that company's coveted trade name. Eventually, all this morphed into something called Innovia Films, Ltd., which took on a refound British corporate identity for its international chain of factories. This included Tecumseh, by that point the only remaining facility manufacturing classic cellophane in the United States.[41]

Cellophane may have retreated to Tecumseh, but viscose film was on a forward march in the United States. Cellulose film for processed-meat casings, cellophane by another name, has occupied a strong market niche because it is an ideal product for industrially prepared sausages. The casing serves as a

cooking mold that is peeled off by the manufacturer before sale to the ultimate consumer. The manufacture of cellulose casings may be a source of worker exposure to carbon disulfide, but it makes the skinless weenie possible. The U.S. standard bearer in this industry has been Viskase, founded as Visking back in 1925, adjacent to the Chicago stockyards. Today it has a multinational presence as a manufacturer of synthetic polymers as well as viscose-based casing products. The latter is still a mainstay, especially Viskase's trademarked Nojax brand.[42]

The casings trade was lucrative enough to engender competition. A new corporate identity, Viscofan, emerged in 1975. Also based in Illinois, it too evolved into a major multinational sausage-casing enterprise. In 2006 it gobbled up Teepak, the old Chicago casings maker that NIOSH once had studied. This was only one of multiple acquisitions by Viscofan. In addition to cellulose, Viscofan makes casings out of collagen and plastic and has manufacturing plants on four continents.[43]

The trajectories of rayon, cellophane, and cellulose casings tell much of the U.S. viscose story, but not all of it. In the late 1940s, three former DuPont scientists hit upon, and patented, a manufacturing process through which myriad small air pockets could be introduced into the carbon disulfide–cellulose regeneration process. The building blocks of this novel method were oxygen, cellulose, and, for good measure, oxygen again. O-Cel-O was born. It was an immediate hit, a success "tied up with the attractive, pastel-colored cellulose sponges which have been so popular with housewives (and their car-washing husbands) ever since World War II."[44] O-Cel-O also benefitted from a timely natural sponge blight in the Caribbean and the aftermath of wartime shortages for Mediterranean supplies. In 1952, the founders sold out to General Mills for a hefty $3.4 million (more than $30 million today, inflation adjusted). The company changed hands again when 3M purchased the Tonawanda plant outside Buffalo, New York, in 1990. In 2006, 3M went on to acquire its only major U.S.-based sponge competitor, the Nylonge Company of Elyria, Ohio (formerly the Sponge Company of Cleveland).[45]

O-Cel-O's real competitor, however, has been in Europe, not Elyria. Founded in France in 1932, Spontex predates its American rival.[46] Spontex has a leg up in another way too: it has an adorable mascot. The Spontex hedgehog has gained fame worldwide, including in the United States. One the best-known television spots with the mascot, released in 2000, featured the creature humping a Spontex sponge in a manner invoking of the scandalous choreographic climax to Nijinsky's ballet "L'après-midi d'un Faune."[47]

However cute Ernie the Hedgehog may be, viscose sponge making may be every bit as efficient a source of carbon disulfide exposure to its workers as

rayon or cellophane. A 1984 study in a sponge factory in France, the only one of its kind in the open scientific literature, found short-duration exposures to carbon disulfide to be as high as 100 ppm.[48] Inhalation of fumes at this high level certainly would be dangerous for any prolonged work, even if not a heavy enough dose to induce the hypersexual behavior that Delpech had chronicled among the poisoned rubber workers of Paris more than a century before.

As rayon went offline in much of Europe and North America in the last decades of the twentieth century, the jobs lost in that sector of the viscose industry might have been matched by a parallel decrease in the number of manufacturing workers exposed to carbon disulfide. This was not the case. There still was money to be made in viscose rayon, simply not in Flint or Coventry or Nitro or Front Royal.

Japan really set the business benchmark for offshoring rayon back in 1964, when it began exporting its viscose industry to South Korea—lock, stock, and leaky barrel. Underwritten with Korean governmental loans, old equipment from the Toray Company, formerly Toyo Rayon, was transferred to the Heunghan Synthetic Fiber Company, which went on to become the Wonjin Rayon Company. The lessons that easily could have been learned from Japan's experience with carbon disulfide poisoning in previous decades were conveniently ignored, most importantly the need to adequately enclose the machinery and use appropriate ventilation to draw away the toxic fumes.[49]

The first case at Wonjin was noted in 1981, although its cause was misattributed to sulfur dioxide, a chemical not present in the work environment. Up until that time, it seems, Korean doctors had never heard about the hazards of carbon disulfide. This changed in no small part because of the activist role of a key clinician involved in the workers' care, Dr. Rok Ho Kim.[50]

Wonjin closed in 1993, but the chronic, long-lasting effects of carbon disulfide poisoning did not cease. By 1997, there were 600 known cases of rayon-related disease among the workers of the former factory; by 2004, over 900 in total had received financial compensation. The Wonjin Foundation for Victims of Occupational Diseases was founded; it established the Wonjin Green Hospital (in Kuri City, South Korea) both to treat the many patients who needed care and to disseminate new medical findings.[51]

The Wonjin tragedy yielded one document that is unique in the long history of carbon disulfide. Kyung-Yong Kwon was hired at Wonjin in 1977, initially became ill in 1985 (including features of psychosis), and in 1988 was pensioned out on full disability. In 1991, Kyung-Yong Kwon committed suicide. What is remarkable is that his suicide note was made public. Writing to his son, Uoon Chun, Kyung-Yong urged the family to continue to collect his

disability payment (the equivalent of just over $200 a month) and, in order to do so, not to report his death until he would have been ninety years old: "It is okay. I am not shameful about it because I acquired illness from working at Wonjin Rayon and die from the illness after suffering for many years. Fight with Wonjin and fight with the Department of Labor. Keep up the fight."[52]

The Wonjin factory left another legacy. Its old equipment changed hands again, destination this time: the People's Republic of China. The PRC was the next to join the Asian rayon-manufacturing boom, and in a big way. One perspective on the changing geography the rayon business comes from the vantage point of Ing. A. Maurer, SA. This industrial engineering firm, based in Berne, Switzerland, provides industrial design expertise to rayon and cellophane manufacturers. Maurer maintains a detailed list of its clients, dating back to 1931.[53] Maurer has done work around the world, servicing, at one time or another, Enka, Courtaulds, Glanzstoff, Lenzing, Mitsubishi, and Svenska Rayon. In the mid-1960s, it became involved in setting up the Formosa Chemicals & Fibre Corporation, which has remained an active rayon staple producer in Taiwan.[54] Since 2000, though, much of Maurer's business has been in China, working with a series of entities whose names come less trippingly off the tongue: Sateri (Fujan) Fiber Company; Longda (JianXi) Differential Fibre Company; Shandong Yamei Sci-tech; and the Weifang Henglian group (a cellophane manufacturer).

International production figures bear this out. Viscose manufacturing capacity in China quadrupled in the first decade of the twenty-first century and now accounts for approximately 60 percent of worldwide production.[55] Much of the equipment used in China may be modern, but that does not guarantee safety. That depends on how it is used and maintained. Thus, the health status of the Chinese viscose-making labor force may be compromised, but the true extent of the problem can only be guessed at. The smattering of medical reports that have appeared indicate that carbon disulfide exposures routinely exceed officially set limits. For example, a 2012 study from the Occupational Disease Prevention Hospital in Nanjing, China, found that more than 10 percent of the rayon workers examined complained of numbness, and a similar proportion showed abnormalities during electrical nerve testing. So much for disease prevention.[56]

Of the conditions inside viscose factories elsewhere in Asia, even less is known. India, Indonesia, and Thailand have become major rayon-manufacturing hubs; in the aggregate, not a large as China, but nonetheless accounting for one quarter of international production.[57] Aditya Birla Group, based in India, is emblematic of today's viscose industry. Birla has powerful

rayon staple (Grasim) and rayon fiber (Aditya Birla Nuvo Limited) manufacturing arms; its reach further extends to subsidiaries in China, Indonesia, and Thailand; and to guarantee a supply of raw materials, its holdings encompass joint ventures in Canadian and Swedish pulp, and development is in the works for a new pulp plantation in Laos.[58]

There are virtually no published biomedical data on the health of these South Asian and East Asian workers, including those employed by the Birla group. But there was one fascinating report from the world of postcolonial studies: a paper by the anthropologist Christopher Pinney, ponderously titled "On Living in the Kal(i)yug: Notes from Nagda, Madhya Pradesh."[59] Nagda is an industrial town where Grasim has a major rayon staple plant. *Kaliyug,* the author explains, is our current epoch, or *yug,* the final one of a repeated cycle, marked by the moral decay of the modern, machine age. Thus, the rayon plant is important not for its very real hazards, but rather for its symbolism:

> Pollution and health and safety issues in and around the factory have been key concerns for several decades and this, combined with the continuous shift system and division of labour, embodies industry as the apparently (negative) antithesis of the rural. This is certainly the perspective of local high-caste village employers who articulate a very negative view of the factory, seeking to project it as part of the degenerate kaliyug which is associated with machinery, the goddess Kali, and a dangerous and unstable modernity. Local village-resident factory workers, however, value the comparatively high industrial wages, shorter working hours, and their liberation from the oppressive expectations of rural "patronage." The complex everyday predicaments of living in the kaliyug are explored through a variety of different voices which suggest the inadequacy of trans-local narratives of industrialisation.[60]

Pinney reports that air levels of carbon disulfide in the Nagda churn room had been documented at one point to be twelve times as high as the Indian legal limit. If that was the case, the exposure in the spinning room, which typically far exceeds that around the enclosed churns, must have been off the charts. The overexposure is not surprising: at Nagda, Gasim was running old, hand-me-down British equipment, just as the Koreans (and later the Chinese) had done with Japanese factory machinery. Pinney also comments that among the complaints linked with facility by the local populace were paralysis, heart attack, mental illness, and, prominently, impotence. This last problem is a classic manifestation of carbon disulfide toxicity. But according to Pinney, impotence is just symbolic. Taking a page from Professor Charcot's work on hysteria and then deconstructing it with a Derridean flourish, Pin-

ney interprets this illness as not so much real condition as a representation of a projected concern of "higher-castes' anxieties which they choose to map on the bodies of factory workers."[61]

Whatever attention has been given to rayon in the region, there has never been an exposé of Asian viscose manufacturing on par with the scrutiny given to microelectronics in *Nightline*'s "Trip to the iFactory" segment in 2012, which reported on the suicide nets placed by Foxconn to catch the assembly-line workers driven by despair to jump from the factory roof.[62] Microelectronics manufacturing has its share of toxic chemicals, but carbon disulfide is not among them. All the same, there is a resonance between Foxconn in our own time and the defenestration of crazed vulcanization workers in the nineteenth century. Indeed, the legacy of vulcanization lives on in other ways, too. Long since phased out as a direct agent of vulcanization, carbon disulfide nonetheless has persisted in the rubber industry. This is because the chemical is used to make the specialty accelerator chemicals that replaced carbon disulfide in its pure form.

Rubber industry workers synthesizing accelerators from carbon disulfide continue to be threatened. In 2014, a scientific study of an otherwise unnamed "rubber and plastic manufacturing plant in New York State" was released.[63] Compared to other employees of the factory, shift workers exposed to carbon disulfide while making rubber-vulcanizing accelerators were afflicted by more than double the expected rate of death from heart disease. The factory in question has been the subject of many medical investigations over the years because of the multiple toxic chemicals used there. In 2013, for example, an investigative report from the Center for Public Integrity traced the history of a bladder cancer outbreak there due to a chemical called ortho-toluidine. That report did not refrain from naming the facility, the Goodyear Tire and Rubber in Niagara Falls, even noting that its workers have a nickname for the place: they call it the "ginch."[64] This term of endearment may or may not be related to slang originating from Canada meaning men's briefs.

When it was discovered that certain substances used to make rubber accelerators not only promoted vulcanization but also interfered with the human body's capacity to fully break down alcohol, an entirely new carbon disulfide problem emerged.[65] Although a perturbation in the metabolism of alcohol might seem like a clever way to extend a binge, the intermediate chemical that builds up not only is not very nice (good-case scenario: severe vomiting), but can even lead to a life-threatening fall in blood pressure. This very adverse reaction is the rationale for deliberately administering this

chemical to alcoholics, generically known as disulfiram and marketed by prescription as Antabuse.

Over and above its acute intended reaction, there are some peculiar "side effects" of long-term Antabuse use. A prominent one is damage to the distal nerves of sensation; questions also have been raised about brain effects and even about an increased risk of atherosclerosis.[66] It has been argued that these problems merely reflect residual damage from long-standing heavy alcohol intake, the wages of past abuse. There is a catch, though. Antabuse itself is broken down like any other medication, metabolized on the way to its excretion. The salient issue for disulfiram is that in the human body, it breaks down to carbon disulfide. The metabolic fate of disulfiram is so predictable, in fact, that it has formed the basis of a simple breath test designed to detect carbon disulfide exhaled by those taking the medication, in order to better gauge adherence to the drug regimen.[67] The commercially marketed testing device that does this is named the Zenalyser, an unintended invocation of the "Moment of Zen" segment that closes the satirical television program *The Daily Show,* often highlighting the intersection of the absurd and the tragic. Disulfiram, as it turns out, may be an effective carbon disulfide delivery device, but recent evidence shows that it may not work that well to stop alcohol abusers from drinking.[68] Nonetheless, disulfiram continues to be approved for human use, although carbon disulfide was itself was removed from the medical pharmacopeia long ago, and even its limited use in veterinary practice (primarily to treat parasites in horses) fell out of favor precisely because of its toxicity.[69]

Carbon disulfide has made another comeback as well, not through pharmaceuticals but via agribusiness. True, the phylloxera epidemic is long gone, and even though carbon disulfide held sway as the gopher killer of choice for many years, that use too eventually fell away. Last to go was the application of carbon disulfide as a grain storage fumigant. One of the preferred carbon disulfide grain treatments mixed it in a 1:4 ratio with the liver toxicant carbon tetrachloride, a product commonly known as "80/20."

This fumigant cocktail posed a real danger. In the 1980s, a research group at the University of Wisconsin put out a call for 80/20-exposed grain workers with neurological symptoms to come in for evaluations. In the end, twenty-one affected persons were recruited. Those that had worked in grain elevators had experienced some of the worst exposures. Case 5 in the series, for example, was a sixty-three-year-old grain elevator worker who had retired after twenty-five years of labor, the first nine years spent doing active fumigation with 80/20 on up to ten railroad cars at a time: "While he would stand on the grain surface inside the car, he would reach over a temporary wall and grasp a 19-L (5-gal) pail of undiluted, liquid fumigant that was

passed up to him by another worker on the ground. He would then wade through the grain to one end of the car and dump the pail across the width of the car. After retrieving the second pail, he would repeat the procedure at the other end and then 'scramble over the wall and out of the boxcar.' "[70]

On medical examination, case 5 showed classic findings of Parkinsonism as well as other evidence of peripheral nerve damage. In comparison, case 11 was a little better off in the extent of his neurological disease, but then again, he was younger. A twenty-nine-year-old, he had replaced the previous worker when he retired; the younger man benefitted from a technical innovation in fumigant application: he used a spray hose rather than a carrying a pail. It was not until 1985 that 80/20 finally was pulled off the U.S. market. This was after the EPA required new company tests—not over concerns about workers' health, but out of fear that chemical residues in consumer products might be too high. Margie Williams, a spokeswoman at the time for the National Association of Wheat Growers, voiced her clients' displeasure at losing a popular product: "[It is] easy to use by a farmer. . . . He can get a good bug kill." [71]

Exit the direct use of carbon disulfide for grapes, gophers, and grains—enter metam sodium (aka metham or carbam, depending on the manufacturer or seller). Metam sodium is a chemical pesticide fumigant used to treat soil to eliminate a variety of pests of a number of different crops. Just as carbon disulfide was finally being eliminated in the 1980s, metam sodium came quietly into commerce. Then, one night in 1991, the derailment of a train that included the fumigant in its cargo dispersed a toxic fog that settled over small town of Dunsmuir, California, and liquid metam sodium percolated into the adjoining Sacramento River. Virtually all plant, fish, and insect life along a forty-mile stretch of the river was killed. Humans along the banks suffered from intense irritation of the respiratory tract, and some went on to suffer from persistent asthma.[72]

As it turns out, once released into the environment, metam sodium quickly breaks down to form several new toxic materials. One of these breakdown products, a strong chemical irritant, appears to account for the asthma outbreak at Dunsmuir. It is called methyl isothiocyanate, a variant of the far more lethal poison methyl isocyanate (the release of MIC from a Union Carbide chemical plant in Bhopal, India, in 1984 killed thousands). But there is another important breakdown by-product of metam sodium, in fact the chemical precursor from which the pesticide is synthesized in the first place—carbon disulfide.

Metam sodium has many potential uses, which means that there are many scenarios for associated carbon disulfide contamination. The long list

of EPA-approved target crops for soil pretreatment with the agent runs the gamut from alfalfa and amaranth to yams and zucchini.[73] And whenever metam sodium comes in contact with the open environment, its breakdown products are inevitably released—the mix seems to depend on specific conditions. When a farmer in France, for example, disposed of some unneeded metam sodium by putting it down a residential sewer, multiple residents on the same street suddenly experienced a foul odor coming from their toilets. The air measured above the sewer manhole detected more than 100 ppm carbon disulfide.[74]

As if the metam sodium story wasn't enough, only a few years ago the EPA decided to pull the plug on another soil fumigant that didn't break down just *some of the time* to yield carbon disulfide; it was designed to turn into the toxic chemical 100 percent of the time. Technically called sodium tetrathiocarbonate, this carbon disulfide delivery agent went by the catchy commercial name Enzone. Originally a DuPont product, in 2004 the manufacturing rights were taken over by a pesticide company based in Japan that was looking to expand its portfolio.[75] That company, Arysta LifeSciences, was attempting to ramp up its soil fumigant business in a big way. Along with Enzone, it was also behind a product named Midas. The fumigant with the golden touch was a cancer-causing, neurotoxic chemical called methyl iodide. In 2011, the EPA responded to the "voluntary" withdrawal of sodium tetrathiocarbonate by Arysta with the formal cessation of its approved use.[76] This had included application on grapes to treat none other than (blast from the past) phylloxera. In 2012, Arysta took methyl iodide off the U.S. market, just before it was about to lose an embarrassing legal battle in California over the manner in which it had gained approval by state regulators.[77]

These have been only minor setbacks for the company. Its market is still wide open internationally. In fact, Arysta LifeSciences' global presence was strengthened with its 2015 purchase by Platform Specialty Products Corporation, linking it with two other major players in the agricultural chemical field (Agriphar Group and Chemtura) to create an "integrated agricultural chemicals segment" with targeted annual sales of $2.1 billion.[78]

Carbon disulfide and all the products and applications connected with it have had their ups and downs over the years. Despite that inconstancy, viscose rayon has demonstrated considerable staying power as a cultural icon, if nothing else. Indeed, that somewhat tawdry *kunstseidene Mädchen* flashiness once connected with rayon seems to have persisted, albeit overlaid with an element of retro playfulness. Or as the Miami Standard Hotel hostess and lifelong local resident Brittany Marissa was quoted in a *Hemispheres Magazine* photo spread in 2012: "Miami used to be all about rayon and tight

dresses, very clubby. Now it's a bit hipper. I feel it's laissez-faire—anything goes."[79]

Brittany seems to have a fictional soul mate in Elle Woods, the heroine of *Legally Blonde*. When a saleswoman at a boutique underestimates her ("There's nothing I love more than a dumb blonde with daddy's plastic") and tries to foist on Elle last year's model as current, she asks, "Is that low-viscosity rayon? With a half-loop top stitching on the hem?" The saleswoman attempts to bluff her, "Of course. It's one of a kind." To which Elle replies, "It's impossible to use a half-loop stitching on low-viscosity rayon. It would snag the fabric. And you didn't just get it in—I saw it in the June *Vogue* a year ago. So if you're trying to sell it to me for full price, you've picked the wrong girl."[80]

Even if rayon as a cultural reference now can be glossed as hip in a feminine context, viscose rayon still retains an old connotation of cheesiness for men, epitomized by Kent in *Animal House,* the would-be legacy pledge who wears a 90 percent rayon clip-on tie his mother bought for him. This same theme was carried through in a 2004 Steven Colbert bit on Pervez Musharraf's pardon of a physicist who had traded in nuclear secrets; the comedian equated "atomic bombs from Pakistan" with "rayon leisure suits from Guatemala," both being part and parcel of the same global economy.[81] And for men at least, the sinister element that infused the Mussolini-period *Agent in Italy* was retained by Dexter Morgan, the fictional forensics-lab-worker-cum-serial-killer with a tendency to wear rayon: "The crime-lab gang didn't wear suits. Rayon bowling shirts with two pockets was more their speed. I was wearing one myself. It repeated a pattern of voodoo drummers and palm trees against a lime green background. Stylish, but practical."[82]

The popular-culture gender gap for rayon is most explicit in a *Law and Order* episode in which assistant district attorney Jamie Ross is subjected to the sexist musings of an aging Judge Marks. She exploits his Neanderthal tendencies by wearing an alluring silk blouse to obtain a favorable ruling. When her boss, Jack McCoy, asks whether she would model silk again for Marks if the need arose, Jamie replies, "Trust me, he would have been just as big a fan of rayon."[83]

Cellophane also has retained a symbolic presence. In John Updike's pivotal *Rabbit, Run,* cellophane makes multiple appearances, including as a covering for laundered shirts, cigarettes, and hotdogs. Harry "Rabbit" Angstrom balances at the fulcrum of the sixties, when cellophane still retained the power to make the everyday object seem just a little bit special. But cellophane was about to enter a new age, going from moderne to postmodern and even taking on a bit of a psychedelic tint. In the same year that Updike's novel appeared (1960), Frank O'Hara's poem "Second Avenue" was published

(although written earlier), spinning the image of "tabletops of Vienna carrying their bundles of cellophane to the laundry."[84]

By the time the 1960s were in full swing, cellophane had gone psychedelic, implicitly in the polychromatic flowers of "Lucy in the Sky with Diamonds" and explicitly in "Cellophane Symphony" by Tommy James and the Shondells. Meanwhile, the old political imagery of cellophane, first popularized by Postmaster Farley in the 1930s, still had legs, transubstantiated into "Mr. Cellophane" from the musical *Chicago,* but then applied metaphorically to any politician without substance or to too much governmental transparency.[85] Cellophane has even been political fodder for Sarah Palin, who, in eat-what-you-kill mode, noted on her self-hosted television reality show, "Our meals happen to be wrapped in fur, not cellophane."[86]

Even though cellophane and viscose rayon are produced by the same chemical process, both entirely dependent on carbon disulfide, this enabling poison remains virtually unknown by the general public. Carbon disulfide does not stand as an icon nor serve as any kind of popular-culture metaphor. The chemical makes a cameo appearance in the technical details provided to underpin an invented Soviet viscose plant called Solkemfib in a postmodern novel from 2010 called *Red Plenty.*[87] But the closest carbon disulfide ever came to a leading role was in the soap opera *General Hospital.* Lord Larry Ashton, it seems, was scheming to corner the market on carbon disulfide, conveniently produced at a Port Charles cannery. The nefarious plot was eventually thwarted by the Port Charles Police Department, and the dangerous carbon disulfide stockpile was destroyed.[88]

Carbon disulfide may have been removed entirely from the mythical Port Charles, but the chemical is still very much a part of an ongoing and indeed expanding viscose-manufacturing industry. Worldwide, rayon production doubled in the twenty years from 1990 to 2010, led by Asia but with an important European presence.[89] Novel, high-tech applications of specialized forms of rayon have filled new market niches, for example, Outlast fibers, which has special thermal properties, was first developed for NASA, or as the promotional materials read, "Tested in Space, and Right Here on Earth."[90] Indeed, NASA has been no stranger to high-tech rayon. Viscose fiber was the basis of a carbonized derivative that was essential to insulating the nozzles of reusable solid rocket motors. The rayon for this formerly came from the North American Rayon Corporation (NARC). When NARC went out of business, NASA stockpiled its product and then embarked on a "NARC Rayon Replacement Program." NASA settled on Avtex; the *Challenger* disaster in 1986 and the consequent interruption in this lucrative product line was cited as one of the drivers in Avtex's failure in 1988.[91] Proving that even the

modest sponge can be cutting-edge too, biotech has been exploring a viscose application, this one based on a specialized viscose cellulose material used to cover wounds.[92]

Another relatively new application for viscose is to turn rayon fibers it into very finely chopped-up pieces, smaller than those in staple. As it turns out, this process brings with it its own novel hazard. In 2007, respiratory problems were linked with work in a factory using this form of fiber, news that was particularly disturbing because rayon had never been known to cause lung disease. In the trade, such finely cut fibers are known as flock. A major use of flock is the coating of cloth or paper to produce a faux-velvet surface: the greeting card industry is a big market for flock-treated paper. Flock can be made from any number of synthetics, including rayon, nylon, and polyethylene. The workers at greatest risk from rayon flock were the ones who used air hoses to blow away the flock waste that collected in the machinery every day. It is small comfort that this potentially debilitating condition is not specific to rayon—nylon and polyethylene can cause this problem too. When the human respiratory system is the machinery that gets clogged, the disease is simply known as "flock worker's lung." The medical report on rayon-caused flock worker's lung shied away from identifying the factory where this outbreak occurred, but a governmental report pinpoints it as a Hallmark facility in Lawrence, Kansas.[93]

Technological innovation is only one newfound selling point for viscose. In a real tour de force of corporate chutzpah, today rayon is marketed as an eco-friendly, nearly green product. Austria's Lenzing, for example, trumpets the ecological aspects of its trademarked Modal line of viscose. The wood pulp for Modal comes from renewable beech trees, and Lenzing proudly displays a Programme for the Endorsement of Forest Certification logo in its promotional materials. Lenzing touts its manufacturing system as being so environmentally responsible that the company even has named the process "Edelweiss technology," a carbon dioxide–neutral production method "as pure as the edelweiss flower," using "renewable and natural raw material" (that would be the wood pulp, not the carbon disulfide).[94] This may indeed be a relatively well-controlled production process that minimizes worker and environmental exposure, but at the same time, Edelweiss invokes the eco-shopping-driven cha-ching of cash registers, which must be the sound of music to Lenzing's ears.

Unlike Model, the other major Lenzing product, Lyocell (Tencel), is made by a process free of carbon disulfide, but it is not an entirely natural product either. Just as the word "synthetic" is avoided in its marketing, Lyocell's key synthetic solvent component, NMMO, may have a clean bill of health so far, but that is only a default status. It has been so little studied to date that its

potential toxicity may become evident only with later investigation.[95] Lenzing also has made a cooperative agreement with a German-based company, Smartfiber AG, that allows it to modify Lyocell. Modify how, you might ask? According to the Smartfiber website: "You will be surprised to learn that textiles can include the best of seaweed, care for your skin, and protect your body; all while also feeling incredibly soft."[96] Along with this promotional copy, the webpage includes the image of a female figure sitting in a yoga position on a beach at dusk (she may be naked, but her back is to the viewer and the photograph was taken a bit too far past sunset to be sure). The message: by the addition of pulverized seaweed, SeaCell rayon not only is a boon for the ecosystem, but is even healthy for you! It is enough to make an edelweiss blush.

Cuprammonium rayon—the old Bemberg silk—also does not use carbon disulfide. The industry leader in its manufacture is the fiber division of the Japanese conglomerate Asahi-Kasei. The manufacturing of Bemberg, also marketed as "cupro," may be free of carbon disulfide, but it nonetheless is a chemically intensive process. That does not stop Asahi-Kasei from promoting it, too, as eco-friendly, emphasizing that Bemberg uses cotton feedstock as its source of cellulose, and omitting any mention of other chemicals.[97] And Bemberg is perceived to be anything but the cheesy viscose of a menswear bowling shirt or cheap necktie. Indeed, it has made something of a presence for itself as the ne plus ultra of suit linings, preferably bespoke. Thus, the *New York Times* described one 2004 creation, available for only a mere $2,750, as a "flawlessly constructed cascade of inside pockets on a Bemberg-lined Oxxford suit."[98]

Bamboo-derived pulp has been used as another pitch to appeal to the eco-friendly shopper. But when marketers leave out the fact that the "green" bamboo-based fiber they are pushing still is rayon, they cross a legal line that the U.S. Federal Trade Commission (FTC), in a crackdown on such false product claims, labeled "bamboo-zling."[99] At least one eco-marketing website hit back at the FTC, implying that that agency's motivation was to protect government-subsidized cotton, which is a far less environmentally friendly crop. Carbon disulfide is never named, although Greener Ideal does acknowledge that "unfortunately, in order to produce fabric that is at all soft from either bamboo or cotton, chemicals (and some harsh chemicals at that) are required."[100]

Nor does cellophane wish to be left out in the eco-unfriendly cold. The industry leader, Innovia Films, continues to make cellophane in plants at Tecumseh, Kansas, and Wigton, United Kingdom (still insisting on putting a™

on the long-since-generic product name). But it also has introduced a new product line, NatureFlex. Innovia Films promotes this packaging material for its biodegradability (organic food sellers have signed on to its use). In July 2015, the company took this one step further, announcing the same endorsement received by Lenzing: "Innovia Films now uses only FSC (Forest Stewardship Council) and PEFC (Programme for the Endorsement of Forest Certification) certified wood pulp in the manufacture of its NatureFlex product."[101]

Elsewhere in its promotional materials, Innovia acknowledges that NatureFlex, just like traditional cellophane, is manufactured through the viscose process. Any mention of carbon disulfide, however, is discreetly omitted. Unsurprisingly, Innovia did not announce with similar fanfare that OSHA had slapped it with fines totaling $112,500 in January 2014 for a series of serious violations at Tecumseh. Many of these involved the plant's handling of carbon disulfide, although it is unclear whether inspectors took any air measurements. OSHA seemed more worried that workers might fall off a carbon disulfide tank ("Employee(s) connecting a metallic transfer hose on top of the Carbon Disulfide tanker were exposed to a fall hazard of approximately 12 feet due to no fall protection system being provided") or get caught in a solvent-caused conflagration ("Employee(s) were exposed to release of extremely flammable vapors to atmosphere that historically result in fire/explosion hazards leading to injury and death to persons in the workplace").[102]

Even the old viscose-based bottle-capping product known in the trade as a viskring in Britain and a cellon in the United States has reinvented itself as a protector both of the consumer and of the environment, asking its potential customers, "Do you have problems with tamper evidence or counterfeit issues? Are you an environmentally conscious producer looking for recyclable packaging?"[103]

More than anything else, the key to success for any "rayon is green" or "cellophane is biodegradable" public relations campaign is the self-focus that is axiomatic to the consumerist equation. As long as the final product is safe, why does it matter that there may be a hazard in manufacturing it? The very first question I am asked, invariably, whenever I talk about carbon disulfide and viscose is "Is rayon safe to wear?" Interestingly, an atoms-for-peace promoter in the later 1940s suggested adding radioactive sulfur to carbon disulfide, and thus any residual chemical in the manufactured rayon could be traced with a Geiger counter.[104] Not to worry. Any carbon disulfide that might have been in the fiber would have long since vaporized into the workroom back at the factory well before it ever got to the savvy shopper.

The consumer blind spot that keeps the wounded worker out of sight is not new. In 1823, a children's book meant to inform juveniles about the how everyday products were made saw the need to educate on this subject. After describing the Staffordshire pottery trades, *Little Jack of All Trades, or, the Mechanical Arts Considered in Prose and Verse Suited to the Capacities of Children,* cautions its young readers to be cognizant of the health toll that this "pernicious" work takes on those employed in making beautiful china. Any admiration these objects inspire should be mixed with regret: "In viewing any article which contributes to our pleasure or domestic advantage, we should enquire of ourselves whether it has caused great inconvenience and painful confinement to the maker, or been the cause of shortening his life one moment."[105]

Remarkably, even after two centuries of human experience with carbon disulfide and extensive research spanning the course of modern biomedical investigation, new knowledge about its hazards continues to emerge, and resistance to the dissemination of such knowledge continues just as strongly as ever. In 2000, for example, a case of progressive kidney disease, a newly reported toxic effect, was linked to carbon disulfide exposure in a rayon factory spinning room. The treating physicians had to resort to the Freedom of Information Act in order obtain the measurements that documented the excess exposure the worker had endured.[106]

That report appeared just in time to be included in the latest extensive rereview of carbon disulfide safety by American Conference of Governmental Industrial Hygienists (ACGIH). The ACGIH finally had come to agree with NIOSH, in 2006 accepting as its exposure limit a reduction by a factor of ten, down to 1 ppm.[107] This non-legally-binding recommendation has had no impact on the OSHA standard of 20 ppm, which today is still the law of the land in the United States. Perhaps not entirely without coincidence, this degree of legal laxity is matched only by the workplace standards of India, Indonesia, and Thailand, three of the big four Asian rayon producers.[108] Even China, at just below 2 ppm, is far closer to the NIOSH/ACGIH-recommended level, at least officially.[109]

Concern has also been raised regarding carbon disulfide's potency to harm the nervous system as it matures from the period of fetal growth through childhood. The systematic study of this question, drawing on a discipline known as developmental neurotoxicology, has yet to be applied to carbon disulfide.[110] Even for the hazards of carbon disulfide that are clearly established in epidemiologic studies, in particular for central nervous system effects and vascular disease, the precise mechanisms by which this chemical does its damage remain largely a matter of conjecture. For example, the ca-

pacity of carbon disulfide to induce hypersexual behavior, noted among the very earliest observations of Delpech in Paris 150 years ago, is only now starting to come together with deeper understanding of brain neurotransmitters. This is especially relevant to dopamine pathways when they are manipulated in the treatment of Parkinsonism, a disease process that is itself a well-established end point of long-term toxic carbon disulfide exposure.

We also now can show what we long suspected but did not have the tools to see: that brain damage from carbon disulfide can progress with even relatively low exposure. A sophisticated study enrolled workers from eleven Japanese viscose factories and performed two magnetic resonance imaging (MRI) examinations six years later. They found increasing numbers of changes indicative of small areas of "silent" brain infarction.[111] By now, all but one or two of those eleven factories are closed.[112] But the workers made redundant are likely still to be experiencing the effects of their past employment.

One other piece of new knowledge about carbon disulfide is not particularly reassuring. New slow-motion camera footage has captured the fluctuating nature of the flame eruption that underlies the carbon disulfide–based "barking dog experiment." The "barking dog" requires a glass cylinder or tube, nitrous oxide (which may be obtained from a spray can of whipped cream), a lighter, some carbon disulfide, a cavalier chemistry teacher, and a classroom of students. On a YouTube slow-motion video of this phenomenon, a University of Nottingham narrator's voice-over informs us that the only thing that ever went wrong while doing the experiment (for him) happened when the bottom of the tube blew out once. The video, released in June 2013, had over 435,000 viewings the last time I checked.[113]

So it seems that we can count on chemistry students continuing to have the opportunity to have fun with carbon disulfide. Their exposures, barring an occasional blowout, spill, or other misadventure, likely will be low and fleeting. Pesticide breakdown and misuse, or an adverse change of wind direction, will put others at risk. Those taking the alcohol aversive Antabuse are guaranteed to get a pharmacologically active dose of carbon disulfide. Retired workers will experience the aftereffects of their past employment, the lucky survivors falling well into the age where vascular disease and nervous system decline take their greatest toll. The neighbors of viscose facilities can track the factory emissions online via the handy EPA Toxic Release Inventory website: in 2014, for 3M Tonawanda, 424, 000 pounds; for Innovia in Tecumseh, 910,000 pounds; for Vikase in Loudon, Tennessee, 2,000,000 pounds; and since sausage is king, for Viscofan in Danville, Illinois, 3,845,000 pounds of smokestack carbon disulfide, amounts that represent substantial releases.[114] Finally, the current and growing worldwide viscose labor force is more directly in

the line of fire through close workplace contact with carbon disulfide, whether making cellophane or rayon or cellulosic sponges, by whatever trade name, and no matter what claim of Gaia guardianship is made by their manufacturers. As a further testament to this globalized risk, eight workers in China's northern Shanxi province were killed in May 2015 by a carbon disulfide "leak."[115]

Our dystopian futures still hold out the prospect rayon, too. This is explicit in *Brave New World,* set hundreds of years ahead, and implicit in *The Hunger Games,* set at a an unspecified postapocalyptic future date. It is not clear precisely what textiles are manufactured in District 8, but when the movie adaptation's costume designer had to clothe Katniss for the reaping, rayon rather than cotton seemed to do the trick.[116] Not all future vistas are dystopic. The Slovakian architect Eva Bellakova has proposed that one of the former Svit factory warehouses be converted into a "Museum of Industrial Architecture": "Visitors of the museum can go through all the floors and have an opportunity to experience the entire width and length of the original factory open space. . . . Visiting the museum ends on the roof of the building which provides a lovely view of the town and especially the gorgeous High Tatras."[117]

The 2010 documentary film *Ultrasuede: In Search of Halston* underscores the designer's move into mass self-marketing with a brief video clip of an advertisement that Halston made for ITT Rayonier, Inc. This was during a brief period in the 1970s when International Telephone and Telegraph, through its subsidiary Rayonier Canada, was venturing into the wood pulp business. The conglomerate was hoping to make a profit from viscose-industry feedstock production, but it soon got out of that business. Ultrasuede is a polyester synthetic, but Halston was not averse to working with rayon either. In the ITT Rayonier promo, Halston speaks suavely and, looking straight into the camera, notes with assurance, "Rayon. It's going to be with us a long, long time."[118]