

THE ENVIRONMENTAL SUSTAINABILITY OF PAPER

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Over 20 years ago, it was thought that the paperless office (or close to it) would be a reality by 2011. Ironically, since then print volume has actually increased, as people now print emails, web pages, etc. Additionally, paper used for packaging, tissue products and newsprint demonstrate how prevalent paper usage is in daily activity.

The rich history of the papermaking industry in New Hampshire is presented to exemplify the negative environmental impact the paper industry has created as well as the improvements leaders in the paper industry are making to reduce their carbon footprint and clean up their operations. Indeed, when a Life-Cycle Analysis (LCA) is performed, it is revealed how high the carbon footprint and environmental impact really are due to the resource-intensive processes required for the making of paper products. LCA affirms that reducing paper consumption and paper packaging of products can have a significant impact on reducing the carbon footprint of an organization, as well as decreasing costs, and there is, in fact, a recent trend to decrease paper consumption in corporations, primarily because of the high costs of purchasing paper and printing.

This paper posits that although both papermakers and consumers of paper products are finding new processes and technologies to help them reduce consumption and waste, it is nascent technologies and innovations that have yet to be developed that will ultimately alter the papermaking industry for the betterment of the environment. Sustainable solutions are being developed, but more are needed. The decisions by corporations and society today will have a lasting impact on the future of paper.

THE PAST, PRESENT, AND FUTURE OF PAPER

Past: History and Development of Demand for Paper

Paper has been an essential part of human life since it was first created in Ancient Egypt in approximately 3700-3200 BC. More modern papermaking techniques were subsequently developed in China in 105 AD, with perhaps the most substantial production innovation coming in 1282 with the introduction of the paper mill. The invention of the printing press in 1440 created the means to print books, but mass production of paper was still not possible until the Industrial Revolution, when technological advances significantly reduced the costs of papermaking. The processes and materials for making paper evolved in various societies over the centuries, in turn increasing the demand for paper-based products and establishing the paper and pulp industry much as we know it today (Hunter, 1970). The evolution of papermaking and creation of paper products occurred over centuries, not overnight. However, in the past two centuries, advances in papermaking technologies, increase in global commerce, and affordability of paper products have led to alarming increases in paper consumption, which, unbeknownst to most individuals, has caused significant environmental damage.

According to RISI, a global information provider for the forest products industry, the demand for paper products is expected to remain high for the coming decades (“The State of the Paper Industry” [TSOTPI], Environmental Paper Network, 2007, p.v). Although paper consumption has leveled off this century, in developed countries from 1992 through 2005, paper and paperboard consumption increased from 150.28 kilograms per person per year to 172.78. In the US, the increase was 184.54 kilograms per person per year in 1961 to 297.05 in 2005. In 1961 citizens in developing countries, consumed only 3.5 kilograms per person per year, but by 2005, the figure had jumped to 23.55 (World Resources Institute, 2010). What makes these statistics even more dire is the fact that world populations continue to increase, potentially exacerbating the effects of increased demand for paper products.

Present: Environmental Impact of Paper Production

The paper products industry is big business, generating over \$200 billion annually (Paperfacts, 2010, para. 3). The global demand for paper products is significant, evidenced by the more than 350 million tons produced annually. RISI believes that by 2021, the volume will have increased to 579 million tons it is not unreasonable that this forecast will come to bear, given the amount of money flowing into this industry and mankind’s addiction to paper products.

The papermaking process is complex and has far-reaching environmental impacts beyond the simple paper production process, which itself is toxic, resource intensive, and uses chemicals and pollutants that are creating major health issues and environmental degradation. In addition, the deforestation required to obtain paper pulp (the primary material used for papermaking) and the disposal of paper waste products are major contributors to greenhouse gas emissions.

We know that the environment and humans can absorb only a limited amount of toxins before biological systems deteriorate (Wargo, 2009). In order truly to understand the magnitude of the environmental and human impact of papermaking and paper consumption, a life-cycle assessment (LCA) must be used. LCA enables understanding of the entire “cradle-to-grave” industrial systems. When performing the LCA for the paper, industry, there are three key areas to consider: 1) sourcing of materials; 2) manufacturing; and 3) disposal of the finished product. Each has a different negative impact on the environment.

Sourcing.

Following an LCA procedure, the first area to evaluate is deforestation – the result of sourcing the primary material used for papermaking: wood. In the Kyoto Protocol, the global pact to reduce carbon emissions, the paper industry received a “pass” on this issue that an LCA would have warned against. Deforestation is a critical environmental indicator because forests store

approximately 50% of all terrestrial carbon dioxide stocks. (TSOTPI, EPN, 2007, p. 28). Although reforestation is becoming more commonplace, still needed is a focus on sustainable forestry for improving biosequestration, the process by which forests eliminate carbon emission by absorbing carbons through respiration and “eating” through their roots, further reducing greenhouse gases. It is especially important that the paper industry address this issue because more than 40 percent of industrial wood harvest is used for paper manufacturing in the US (“Improve Paper Choices,” 2010, para. 3). An LCA exposes additional environmental impacts on deforestation including: energy consumption for logging, the destruction of natural ecosystems, reduced water quality, soil erosion, diminished habitats for plants and animals, and the elimination of old-growth forests. The sum of the environmental damage for the sourcing of raw materials to create pulp is a cause for much concern.

Manufacturing.

Chemicals are found in most processes used in papermaking, beginning in the forest where pesticides are used (see Appendix A). An array of chemicals is used to process fiber into pulp, resulting in pollution to the land, water, and air. Depending on the product and an individual company’s processes, the range of chemicals can vary from significant quantities, to a just a few chemicals, the most commonly used of which are chlorine, mercury, absorbable organic halogens, nitrates, ammonia, phosphorus, and caustic soda, each of which damages the environment differently. The US EPA has established a valuable tool to help categorize and monitor the use of chemicals, the Toxic Release Inventory (TRI).

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The TRI is a database that contains detailed information on nearly 650 chemicals and chemical categories that over 23,000 industrial and other facilities manage through disposal or other releases, recycling, energy recovery, or treatment. The data are collected from industries including manufacturing, metal and coal mining, electric utilities, commercial hazardous waste treatment, and other industrial sectors (Environmental Protection

Valuable insights can be realized about the environmental effects of chemicals by using the TRI data.

As with most industries, the manufacturing process is the greatest source of ecological problems. The Environmental Energy Technologies Division (2010) of the US Department of Energy estimates that it takes 17 watts of energy to produce one piece of paper. Statistics such as this explain how papermaking accounts for over 12 percent of manufacturing energy use, and, in turn, produces nine percent of the greenhouse gases released in the US by manufacturers (Environmental Defense Fund, 2010, p. v.). Pulp and paper manufacturing produce the third largest industrial emissions of TRI into the air (TSOTPI, EPN, 2007, p. 48).

In addition to the high energy consumption and air pollution that is created in papermaking, the impact on water supplies is striking. Paper manufacturing is an extremely resource-intensive process, for which water is the primary element. According to the US EPA, the paper industry is the largest user of industrial process water per ton of end product (TSOTPI, EPN, 2007, p.3). As water shortages become more commonplace, paper producers are becoming increasingly more competitive for water supplies that are needed for drinking and farming.

As the fourth-largest emitter of toxins to surface water, the paper industry is a major contributor to water pollution (TSOTPI, EPN, 2007, p.3). Effluent wastewater flow from paper mills is of great environmental concern. New technologies and processes are helping to reduce the environmental impact of effluent flow, improvements have been made in the release of dioxins, and the reporting of Toxic Release Inventory has become mandatory, but pollution continues to be problematic and toxic substances have certainly not been eliminated from paper manufacturing.

Disposal.

Disposal of vast amounts of discarded paper products generates another set of environmental problems that is uncovered through an LCA. Paper in landfills creates methane as it decomposes, and it is estimated that 25 percent of all landfill waste is from paper products. The quan-

tivity of methane produced by paper in landfills is 69 times greater than that produced by fossil fuel electricity production and has 23 times the heat-trapping power of carbon dioxide. The EPA has concluded that paper is the single greatest source of landfill methane (TSOTPI, EPN, 2007, p. 4).

Because of the environmental degradation and human health risks associated with the entire papermaking process -- materials sourcing, production and disposal -- the scale of the problem is considerable. The life cycle assessment for paper uncovers the need to find a variety of solutions so that the problem can be adequately addressed.

Business and the Environment

In most businesses, there are companies that are considered more socially and environmentally friendly than others. The papermaking industry is no different. While some corporations have changed to keep regulators away, others are changing because they see change as a necessary function of sustainable business practices. In general, the papermaking industry has improved its overall environmental performance. Yet as in most industries that have a poor environmental track record, there is still much to be done in order for them to maintain environmentally sustainable operations.

Atlanta-based Georgia-Pacific (2010) is a global leader in producing paper products, with operations in over 300 locations in North America, South America, and Europe. Their paper products include tissue paper, traditional paper, and packaging. They also sell pulp products and are a chemical supplier to the paper industry. Georgia-Pacific (GP) is straddling the line between adopting compliance-based programs and actually demonstrating a serious commitment to environmental stewardship.

GP practices sustainable forestry in the United States, and the company's entire procurement of wood and fiber is 100% Sustainable Forestry Initiative (SFI)-certified. When GP purchases wood and fiber from outside North America, however, they "seek to ensure that all our purchased raw material is acquired in a legal and sustainable manner" ("Key Practices," GP, 2010, para.2). With an expansive global reach,

their procurement procedures outside of the US are not nearly as admirable.

Part of GP's compliance-versus-environmental-leader dichotomy can be found in their annual Sustainability Report, which covers a wide range of programs, such as employee, environmental, and community involvement. ("Sustainability Report," 2010, GP, p. 8). While GP should be commended for producing such a report, the report itself lacks details about their operations when compared to some of their competitors' publications. Indeed, GP's definition of sustainability is itself somewhat suspect: as they note, "meeting the needs of society today without jeopardizing our ability to do so in the future" (Defining Sustainability," 2010, Georgia Pacific, popup) This definition combined with their belief that the ultimate measure of a business' sustainability is long-term profitability is troubling. GP also believes that "making products that people voluntarily choose over alternatives means that a business is satisfying a social need" ("Our Approach," 2010, GP, popup). It is clear that profits come first and they are placing the onus on customers: GP is just giving them what they want.

When examined by an LCA for paper manufacturing, Domtar (2010), the largest integrated manufacturer and marketer of uncoated free sheet paper in North America and the second largest in the world, presents an interesting example of a company that has made significant environmental improvement as an organization. Toxic emissions have continued to decrease, and they have lowered greenhouse gas emissions (GHG) by 33.7 percent since 2007. Renewable energy is 77.6 percent of their total energy use, and they continue to increase their use of self-generated electricity. Water consumption and effluent discharges have declined over the same period, and completing the papermaking lifecycle, Domtar has decreased the amount of waste that ends up in landfills by ten percent. For an industry that creates many environmental issues, Domtar is making impressive strides toward improving their environmental performance.

Domtar's downfall is in marketing their products by misrepresenting the negative environmental impacts of the papermaking business. Through a marketing campaign and website,

PaperBecause.com, Domtar is attempting to clean up the image of their industry. The "Paper Because" campaign wants customers to understand how important paper is in their lives by touting how paper is "personal" and "purposeful." From a marketing perspective, it is a creative new way to sell products, but Domtar crosses the line in the section of PaperBecause.com entitled "Fact or Fiction," wherein from an environmental perspective, the only "fact" is the inaccuracy of environmental data produced by Domtar. Six true or false statements are made: 1) making paper destroys forests; 2) paper is bad for the environment; 3) making paper consumes a lot of energy and fossil fuels; 4) paper has a high carbon footprint; 5) recycled paper is always better for the environment than virgin paper; and 6) paper significantly contributes to landfill. Domtar claims each of the statements is false and an explanation is provided as to why. ("Paper Is Sustainable," 2010. Domtar) Individuals and companies that know the scientific evidence regarding the environmental impact of papermaking realize the claims made by Domtar are inaccurate and misleading at best. It is unfortunate that a company that is making impressive environmental improvements to its operations would commit such an ethical error rather than promote their positive changes. Although Domtar would like society to believe that "paper is sustainable," it is not.

International Paper (IP) is a highly diversified papermaking organization. With operations in North America, Europe, Asia, Latin America, and Africa, and revenues exceeding \$23 billion annually, IP's (2010) operations can have far-reaching environmental consequences. Stockholders may be dissatisfied, but environmentalists are pleased that the poor global economy has caused IP to close some mills due to the decreased or reduced demand for paper products.

For such a large corporation, IP is proving to be a leader in improving environmental performance. IP considers the entire lifecycle of paper when greening their operations. Like GP, IP certifies their forest management and fiber sourcing through Sustainable Forestry Initiative, but unlike GP which limits the certification to the US, IP's global operations' compliance is certified by international organizations such as the Programme for the Endorsement of Forest

Certification, the Forest Stewardship Council (FSC) and the Brazilian Forest Certification Standard (CERFLOR). By monitoring their supply chain, IP can be assured that they conform to the highest standards and enforce sustainability programs ("Global Policy," 2010, IP, para.4).

International Paper tracks carbon dioxide, nitrogen oxides, sulfur dioxide, and particulate matter globally, and volatile organic compounds in the US only in an effort to report accurately its air emissions to regulatory agencies. Since 2004 International Paper has decreased sulfur dioxide emissions while nitrogen oxide emissions have increased slightly. Volatile organic compound emissions have decreased by a third as well. IP programs have led to a decrease in GHG emissions of 30 percent and fuel oil and natural gas use by 49 percent per ton of product (U.S only). The financial investments made by IP are not insignificant. By the end of 2008, IP had spent \$250 million on energy efficiency projects ("Sustainability Report," 2010, IP, pp. 18-22).

Regarding water consumption and wastewater, IP has decreased solid waste by approximately three percent since 2004 while increasing the percentage of solid waste that is burned for energy, beneficially applied to land, and beneficially used otherwise. Water consumption has decreased slightly and effluent was lowered by four percent, ("Sustainability Report," 2010, IP, p. 23), even though IP subsequently opened a new mill.

IP is not perfect. As evidenced, some of their environmental practices occur only in specific regions of the world while at other times simply following government regulations is the norm.

The ideal example of a papermaking company that demonstrates its understanding of the environmental effect of its operations is New Hampshire-based Monadnock Paper Mills (MPM). Monadnock is the oldest continuously operating paper mill in the US. When compared to GP, Domtar, and IP, MPM is just a small, privately owned papermaker with global customers. The keys to the success of their sustainable operations and commitment to sound environmental practices are innovation, specializa-

tion, and product diversification, all of which will be discussed in detail later in this paper.

Georgia Pacific's efforts are acceptable, Domtar's are largely positive, and International Paper's understanding of the lifecycle of paper and how to remediate their environmental performance globally is a massive undertaking for such a large organization. Yet if any of these three compared themselves to Monadnock Paper Mills, it would be clear that there is more work for them to do. Even with the extensive improvements many papermakers are enacting to green their operations, solutions for the reduction of paper consumption are essential in order for actual environmental sustainability to be achieved.

Future: Solving the Paper Problem

Forecasts are used as guides by businesses and governments seeking to make sound decisions. But forecasts often overlook innovation, examining only current consumption coupled with demographics. In reality, forecasting the future is extremely problematic. For example, in 1798, based on projected population growth, Malthus declared that food supplies would not be adequate for the number of humans that would inhabit the earth in the future. Yet thanks to innovations in farming, food storage/preservation, and transportation, today food is available to a significantly larger population than when he made his pessimistic predictions in *Essay on Population*. At a United Nations conference in 1992, world leaders predicted "worsening poverty, hunger, ill health and illiteracy" (Ridley, 2010), but the opposite conditions occurred within 10 years. Although it is impossible to predict the future accurately, when one looks at future paper consumption trends through an innovation lens, trends may be more promising. Societies can easily implement changes that will diminish the environmental impact of paper by leveraging proven techniques that are employed today globally, such as recycling and reducing consumption.

In the early 1970s, businesses espoused the vision of the "paperless office." It was predicted that computers and email would eliminate all of the office paper, and even Xerox Corporation promoted the concept. In 1999 Bill Gates,

then Microsoft CEO, wrote about how technology will transform documents from paper to electronic. Yet 40 years after the concept of the paperless office was first touted, the problem has only worsened. In a typical large corporation, the average employee prints over 1,000 pages per month (Tam, 2004). It seems probable that the "paperless office" will never come to be.

Maximizing recycled content.

Nongovernmental organizations (NGO) such as the Environmental Defense Fund, Natural Resources Defense Council, Forest Ethics, and the Recycled Products Purchasing Initiatives are banding together to present solutions to the problems. A "Common Vision" was presented by the aforementioned NGOs and other environmental organizations. The document lists four key action areas for environmental performance improvement: maximize recycled content; clean production processes; source fiber responsibly; and minimize paper consumption.

The Environmental Defense Fund partnered with US paper purchasers, including McDonald's, Duke University, and Time Inc., to create the Paper Task Force. The objective of the Paper Task Force was to perform "an analysis of environmental impacts associated with the entire life cycle of several major grades of paper, reaching literally from the forest to the landfill" (National Research Council, 1997). The study produced many key findings, especially in the comparison of virgin papermaking to recycled content. Although the energy requirements for papermaking using recycled content are higher, the methane produced by land-filling waste and carbon biosequestration by forests balanced the equation, resulting in an overall reduction in carbon emissions for recycled content.

An LCA also illustrates how recycling decreases air and water pollution. Using recycled instead virgin paper could result in impressive environmental benefits. Although it is utopian to believe that 100 percent recycled content could be used, great benefits could be realized by making the change. The total reductions would be:

- Energy consumption – 44 percent
- Net greenhouse gas emissions – 38 percent

- Particulate emissions – 41 percent
- Wastewater – 51 percent
- Solid waste – 49 percent (TSOTPI, EPN, 2007, P. V)

Such compelling statistics provide clear evidence that we must place more emphasis on recycling. Recycling efforts in the US have been expanding continually, but clearly there is still more to be done when only approximately 50 percent of office paper is recycled and 37 percent of pulp is produced from recovered paper (TSOTPI, EPN, 2007, p. v).

Globally, the use of recovered paper has dramatically increased as well. In 1992, developed countries recycled 75.5 metric tons of paper; in 2006, 132.5 metric tons. Although the total volume was much lower, the World Resources Institute (2010) noted that developing countries increased the volume of recovered paper by 365 percent between 1993 and 2006.

Clean production processes-- sustainable forestry.

Recycling is only one part of the solution because paper can be recycled only five to seven times before the pulp fibers are too weak to be reprocessed, therefore necessitating the continuation of virgin wood papermaking practices. Fortunately, deforestation can be greatly limited through sustainable forestry. There are two major watchdog organizations overseeing the forestry industry. Although Georgia-Pacific and International Paper use the Sustainable Forestry Initiative (SFI) for certification, the Forest Stewardship Council (FSC), “an independent, non-governmental, not-for-profit organization established to promote the responsible management of the world’s forests” (“About FSC,” 2010, FSC, para. 1) is more widely used and has greater brand recognition. FSC’s efforts have produced noteworthy results:

- More than 125 million hectare forests worldwide are certified to FSC standards, distributed in over 80 countries (March 2010).
- FSC certified forests represent the equivalent of 5% of the world’s productive forests (July 2009).

- The value of FSC labeled sales is estimated at over \$20 billion (2008).
- With over 16,000 certificates (March 2010), the number of companies along the forest product supply chain committing to FSC certification peaked at 50% in 2008 (“Facts and Figures,” FSC, 2010).

While the efforts by FSC and other NGOs to enhance sustainable forestry have made a dramatic impact on deforestation, other options are available that can further improve responsible fiber sourcing. As pesticides, herbicides and fertilizers are generally considered acceptable forms of sustainable forestry by NGOs and government agencies, FSC also encourages integrated chemicals management, despite possible criticism by environmental groups. Because of the higher cost of producing paper using non-wood fibers, North American paper mills have generally opted for wood fibers. Production of paper using other fibers, such as bamboo, hemp, and straw, is environmentally preferred and is beginning to increase. However, it is still a very small percentage of the total fiber sourcing quantities.

Minimizing paper consumption.

Decreasing paper-based packaging must be a priority for businesses wishing to reduce costs and promote sustainable business practices. Through a pilot program and study to reduce both their costs and their carbon footprint, Cisco Systems, a leading technology corporation, quickly learned the value of decreasing their paper consumption. By eliminating unnecessary packaging, reducing packing materials, and not printing product documentation, Cisco determined that paper consumption reductions coupled with decreased shipping costs would save them \$24 million annually. As part of their Sustainable Value Chain Management Action Plan, they are extending their success by sharing the new techniques with partners, making paper packaging easier to recycle and introducing recyclable plastics into product packaging. Edna Conway, Cisco Senior Director for Advanced Compliance & Social Responsibility, summed it up by stating, "Packaging sustainability provides

empirical evidence that green is good for the bottom line” (GreenBiz, 2010).

United Parcel Service (UPS) is addressing the packaging problem in a broader method. UPS has created an eco-logo called the Eco Responsible Packaging Program that promotes UPS's commitment to the environment and creates awareness for their customers regarding the benefits of reducing packaging. They will evaluate a customer's packaging process for materials use, right-sizing, and damage protection. Customers that meet certain eco-responsible-packaging requirements, can use the logo on all of their shipping packages, demonstrating to the world that they are committed to greening their operations. The eco-logo has the potential to gain wide acceptance because the assessment is certified by a third-party organization and has been endorsed by the Sustainable Packaging Coalition and Business for Social Responsibility for Environmental Leadership.

Packaging is not the only big expense to corporations, as printing costs can be as high as 10 percent of a corporation's revenue (Tam, 2004). Although these costs include copier paper as well as all other print operations, the costs of printing paper alone is massive. If US businesses could decrease their paper consumption by ten percent, greenhouse gas emission could be reduced by 1.6 million tons, which equals the annual carbon emissions of 280,000 cars (TSOTPI, EPA, 2010, p.v.). Because of the high costs and huge carbon footprint of paper and printing, companies are seeking ways to minimize their paper consumption. Many new technologies have been created to help employees and management analyze printing data and change behaviors. Basic actions such as duplexing documents can decrease printing costs 38 percent and save a large corporation hundreds of thousands of dollars annually (“Ruses to Cut Printing Costs,” *Economist*, 2010, September 2, para. 9). Additionally, as document management practices evolve, physical documents are being replaced by digital versions.

Possibly the greatest opportunity for reducing paper consumption will prove to be in products that are becoming more commonplace today, and in the unknown products of tomorrow. New consumer technologies like e-readers and tablet computers will continue to reduce paper

consumption. In 2000, *The Economist* published an article entitled, “Who Wants Electronic Books?” The article cited new reader technologies that were available, the success of a Stephen King downloadable novel, and the fact that some believed that by Christmas the market would be validated. The author was dismissive of the hype affecting other reports. (“Who Wants Electronic Books?”, 2000, October 5). Indeed, in 2008 for example, editors from *Wired*, *Rolling Stone*, *The New Yorker* and *Us Weekly* asserted that the physical magazine would continue to be the prevailing delivery vehicle. (Of course, each of the magazines now has an iPad app!)

It should be no surprise that the transition we have seen to date took a decade to occur. The history of social innovation proves that most new products follow the 10/10 rule. It takes 10 years to establish and develop the right technology platform and another 10 years for mass adoption (Johnson, 2010).

Since e-readers and other electronic devices like computers, smart phones, and netbooks are not limited to book publication, newspapers and magazines will continue to suffer from the competition brought by digital content. eReaders' impact on eliminating paper has not and will not occur overnight, but as the newspaper industry can attest, digital content has had a dramatic impact on paper reduction. The traditional news industry continues to struggle with high structural costs, which results in less printed news content. Furthermore, newspapers have shrunk by printing less content on thinner pages. All of this has occurred even though the cost of paper has seen steep declines. Couple these issues with the fact that younger readers go almost exclusively online for news and do not like to pay for it, one can conclude that the challenges newspapers face are daunting and it can be expected that paper production for news has nowhere to go but down.

Hardware devices like the Amazon Kindle, Apple iPad, Barnes & Noble's Nook and Sony Reader are expected to make up six percent of consumer book sales in 2013. The CEO of publisher Simon & Schuster believes it will be closer to 25% in three to five years (Kopytoff, 2010, para. 4), and eBooks commonly outsell their paper counterparts at Amazon (Sorel, 2010, July 20, para. 1). The Consumer Electronics Associ-

ation released a market research report about shopper spending for the 2010 Christmas season. The second and third ranked electronic devices desired by consumers were the iPad and eReaders respectively. Also in the top 10 were electronic devices that can present published content and also be used as communication devices – laptops (1), iPod/iTouch (4), computer (9) and desktop PC (10) (Fast Company, 2010, para. 3). As these devices become more pervasive, book, newspaper, and magazine publishers will continue to see readers move to electronic content.

These statistics are compelling and do not bode well for paper books, magazines and newspapers, and more electronic, portable devices are hitting the market. BlackBerry maker Research In Motion, Dell, Samsung, and HP are producing tablet computers as well, which will increase the access to digital content. There are environmental issues associated with the creation and disposal of electronic devices. Yet because reading digital books, newspapers, and magazines is not the primary function of most of these devices, a decrease in production of them is unlikely. Furthermore, multiuse products like tablet computers, mobile phones, and laptops may in fact spell the end of the single-use eReader in the coming years – especially in developed countries. But to better understand the disruptive nature of innovation and how the papermaking business may be affected, we must look at what is happening in developing countries.

Led by Nicholas Negroponte, the founder of MIT's famed Media Lab, The One Laptop per Child project is believed to have had a profound influence on how the developing world uses technology and reads books. The low cost laptop is positioned as

a potent learning tool designed and built especially for children in developing countries, living in some of the most remote environments. It is about the size of a small textbook and has built-in wireless and a unique screen that is readable under direct sunlight by children who go to school outdoors. It's extremely durable, brilliantly functional, energy-efficient, and fun. (OLPC, 2010, para. 1)

Tens of thousands of the laptops are being sold in developing countries, such as Uganda, Peru, Rwanda and to aboriginal children in Canada. Negroponte has gone so far as to predict that the physical book will be dead in five years. He stated, "The physical medium cannot be distributed to enough people. When you go to Africa, half a million people want books . . . you can't send the physical thing. We put 100 books on a laptop, but we also send 100 laptops. That village now has 10,000 books. (Combs, 2010, October 17, CNN, para. 3, 4).

Is Negroponte's vision a fantasy? His argument is logical and the success of One Laptop per Child so far adds credibility to his claim. Past examples of innovation that leapfrog current technologies, such as cell phones, enable one to better understand that Western societies are not always good predictors for how developing economies will behave.

For example, in the developing world, land-line telephones are often unheard of because of the large infrastructure costs for providing and servicing them. The result is that there are approximately 4.6 billion mobile phones in use today ("The Apparageist Calls," 2010, October, 28, para. 1). Mobile phones have quickly become the technology choice for the developing and emerging markets. In Brazil, Russia, India, China, and Indonesia (BRICI countries), there are 1.8 billion mobile phones whose uses include obtaining market pricing for farm products and advice for crop planting ("Next Geeks," 2010, September 4,). In Sudan, a company called Txteagle, uses mobile phones to break down jobs into small tasks and send them to many people in remote areas where local knowledge is needed but is inaccessible or cost prohibitive to convey. The person performing the job gets paid through a mobile money service. The Internet-enabled phones can also be used for the delivery of information that traditionally would have been delivered in books and other news sources.

Frugal Innovation

"Frugal innovation" is a process that is becoming more commonplace in responding to service needs of developing countries. The concept is that lesser technologies are created to

provide a much-needed product at a fraction of the cost of a traditional product, as in the One Laptop per Child project. Supplying electricity requires major investments to build the infrastructure. Due to the costs and difficulty in building the network, over 1.5 billion people do not have access to electricity. Many technology firms are creating products such as lanterns using solar-powered systems. Biomass is being studied as a power source for “micro-grids” that can power a village. To help farmers with refrigerating milk, researchers are working on a generator powered by cow manure. The added benefit of such innovations is that they are using much better environmental practices (“Power to the People, 2010, September 2, para. 7-8). Ironically, the innovation that enabled paper product consumption to grow exponentially may also spell the demise of papermaking.

Papermaking in New Hampshire: A Case Study

The story of papermaking in New Hampshire exemplifies both the beneficial and detrimental environmental and economic aspects of the industry as discussed above and provides insight into the future of an industry that has been a prevalent part of that state’s economy for centuries.

Pioneers started settling along the Upper Androscoggin River in the North Country of New Hampshire in the 1780s. Early residents of the area focused on agriculture to sustain themselves until the 1820s when the state’s natural resources – trees and rivers – gave birth to the logging industry in the region. With an abundance of tree varieties and demand for wood products, the timber industry in the North Country flourished. The Androscoggin and Magalloway Rivers were keys to the success of the logging industry, providing transport of timber until trains arrived in Gorham (1851) and Berlin (1855). (The last long-log river drive occurred in 1937, and using rivers for the transport of any timber ceased in the 1960s when International Paper Company and Brown Company began using alternative means to move pulpwood for their papermaking operations.) Loggers har-

vested white pine and red spruce for building materials, hemlock for tanning, tamarack for shipbuilding, white cedar for shingles and balsam fir for boxes. In the 1870s, the pulp and paper industry, which used smaller spruce trees, was established in the region as well. The paper industry grew throughout the early 20th century, and consolidation of paper manufacturers increased industry control and influence in the region. The result was an increase in production and continued deforestation. By the early 1900s, little virgin forest remained in the Androscoggin River valley due to the aggressive acquisition of land and control of the tree harvest by Brown Mills Company and International Paper Company. Fortunately, due to past experiences and innovations in timber harvesting, sustainable forest management principles were established. A subsequent benefit of the regrowth of the forests was the return of many animal species that lost their habitat during the 1800s when clear-cutting the forests was at its peak.

Although deforestation is no longer a concern in New Hampshire, the wider environmental impact of papermaking proved disastrous to the region. For example, the Androscoggin River was one of the most polluted rivers in the US through the late 1970s due to the effluence created by paper mills. The fumes created by the effluent were said to have peeled the paint off houses. Additionally, aquatic life was not sustainable, the rivers in the region contained white foam, and the water’s color was dark and murky. Due to the passage of the Clean Water Act in 1972, the North Country rivers have made a dramatic recovery. And as will be discussed later, the decline of the papermaking industry in NH has led to further improvement of the environment, as have other government regulations.

The forest-based industries are not nearly as large as they once were, and economies in the region are continually shifting to service industries such as tourism and healthcare. In 2001, New Hampshire’s papermaking industry employed only 10,000 people. In 2004, it generated \$333 million in revenue, but the forecast for employment in the papermaking and timber industries is bleak. (“Affected Environment,” Regional and Local Demographics, 2010 US Fish and Wildlife Service). At this writing, the future

of the last paper mill in the North Country of New Hampshire, Fraser Papers, is unknown because a buyer may purchase the mill which closed down on October 13, 2010. The deal has not been completed, nor has a plan to reopen the mill been provided. The closing of Fraser Paper may in fact prove to be the end of the centuries-old papermaking industry for the North Country of New Hampshire (*New Hampshire Business Review*, 2010, November 5, para. 1-5).

Transformation in New Hampshire

Because of the papermaking industry's steady decline in New Hampshire, change and innovation were and are needed to keep the state's economy vibrant. Since the papermaking industry has dramatically reduced the amount of pollution it generates, NH's ecology has rebounded, enabling tourism to thrive and replace many of the jobs that were lost when mills closed. Nokia of Finland is famed for having been a paper mill for 100 years and then transforming into the world's largest mobile phone company. It would be bold to assume that any paper mill could reinvent itself as dramatically as did Nokia, but that does not mean that change has not and will not occur.

The mission statement of Monadnock Paper Mills (2010) exemplifies how a small papermaker can compete on a global scale by leveraging innovation: "We support our mission with the continuous rapid development of new value-added products, high levels of customer service, and continuous operational improvement" ("Aim, Vision, Mission," 2010, MPM, para. 1).

Starting in 1973, and before the US government regulated wastewater, MPM built its own wastewater purification facilities. The company has also taken smaller steps that have led to energy and cost savings. Four years ago, MPM replaced over 1,000 lighting systems with modern lighting technologies. Additionally, 100% of its "short paper" waste is reclaimed during the water purification operations and is provided to local farms for creative uses including compost, animal bedding, and manufactured topsoil.

MPM was awarded the 2010 Greenerpalozza Award for energy efficiency by the New

Hampshire Business Resource Center. At the award ceremony, New Hampshire Division of Economic Development Interim Director Roy Duddy praised MPM, stating, "Monadnock Paper Mills is a model of how businesses can both 'go' and 'remain' green. Long before there was a strong national push to become more energy efficient, Monadnock was demonstrating corporate citizenship of the highest order" (*Business New Hampshire*, 2010, August 26, para. 2-5).

Greenerpalozza is just the most recent award in a long list of gratifying accolades for MPM's environmental performance over the years, including:

- EPA Green Power Leader
- EPA Climate Leader
- EPA Environmental Merit Award
- ISO 14001:2004 Certified Environmental Management System
- Forest Stewardship Council Certified
- WasteWise Partner
- New Hampshire Governor's Award for Pollution Prevention
- NHBSR Cornerstone Award
- Business NH Magazine Lean and Green Award

The aforementioned awards and programs point to MPM's commitment to sustainability through collaboration with governments, non-governmental organizations and employees. MPM exemplifies how corporations can transform industries so as not to be in direct conflict with environmental sustainability. MPM also recognizes that still more improvements can make them carbon neutral. Duddy sums it up best in the statement: "There's no doubt that this company is an example of how a business can not only be profitable, but also be environmentally aware and helpful to its neighbors" (*Business New Hampshire*, 2010, August 26, para. 2-5).

Innovation and entrepreneurship are evident in the establishment of two paper-related New Hampshire software firms that were started specifically to address the digitization of documents, which in turn reduces paper consumption. Founded in Nashua, NH, eCopy produces scanning software that creates images of docu-

ments and integrates them into business processes. There are many other software companies that provide similar functionality, but eCopy is considered to be a leader in this market segment and as such proved to be a vital part of the NH business community. In 2007, eCopy was named the second fastest growing company in NH by *Business NH* magazine. *Business NH's* editor Matt Mowry stated, "eCopy reflects the entrepreneurial spirit that makes New Hampshire a technology hot spot. Their rapid growth clearly demonstrates how local software companies can excel not only in the United States, but also in global markets" ("eCopy Named Second," 2010, eCopy, para. 3).

Unfortunately for the New Hampshire economy, in 2009, the company was acquired and moved to neighboring Massachusetts.

A direct competitor to eCopy is Omtool, a company that has used innovation extensively to improve their products. In 2010, Hewlett-Packard recognized the company by awarding Omtool with the HP Outstanding Partner for Technical Innovation and Collaboration honor. In order to drive additional innovation, Omtool looks to their customers. Firms that use Omtool's technologies in novel applications are presented with the Omtool Drive to Innovation Award ("Omtool Announces," 2010, Omtool, pp. 1-8). Based in Salem, NH for 15 years, Omtool also relocated to Massachusetts, citing the need for a larger office, and the desire to be closer to the technology hub of Boston ("New N. American Headquarters," 2006, Omtool, para. 1-3).

Although eCopy and Omtool are small companies that might be seen as relatively expendable, New Hampshire should be troubled by the fact that two "new economy" firms recently left the state, especially since the economic outlook for the paper industry in New Hampshire is much less promising than the statistics RISI presents.

Summary and Conclusions

Solving the environmental problems paper creates is fraught with challenges. People and communities have relied on paper for centuries, particularly in the last two, and paper consumption is predicted to increase in the foreseeable

future. Like America's addiction to oil, our addiction to paper must also be reversed.

The ecological damage created by papermaking is alarming. The production of paper products requires too many toxic chemicals, is energy intensive, and impacts water supplies. The waste created by papermaking creates massive amounts of toxins that are released into the air, water, and land, which makes the paper industry a leading polluter in the US. Greenhouse gas emissions further add to the predicament. With all of the ecological devastation, it is hard to comprehend why government, business and society have largely ignored the problem.

New Hampshire provides an interesting historical perspective on the papermaking industry, as well as a glimpse into the future. Fortunately, the environment proved to be fairly resilient and was able to recover when given enough time. Tourism and other services are flourishing in New Hampshire, while other companies have been born that digitize documents. Monadnock Paper Mill has leaped well ahead of the industry giants by redefining what it means for a papermaker to employ sustainable environmental practices.

Many solutions exist, but are not aggressively acted upon. Recycling is a method that can be employed for short-term ecological gains, but decreasing the amount of paper used is key to any solution. Businesses are beginning to become conscious of the environmental and cost reduction benefits that can be realized by minimizing the amount of paper used in their operations. Whether it is reducing packaging or print volume, business solutions are being implemented on a wider scale. As more businesses learn about improving processes and saving money, all while reducing their carbon footprint, current and new best practices will become more widespread.

As seen with RISI's predictions on the growth of global paper consumption, historical data, trends, and demographics too often do not factor in the influence of innovation, therefore making the statistics less reliable. Millennials, individuals who grew up with PCs and the internet at their fingertips, are a much larger part of the consumer base and may provide more insight into the future of paper content and documents.

For instance, what is the definition of a document when communication is almost exclusively electronic? People used to send letters; now they send “tweets,” texts, and Facebook posts. Blogging, which can be done only using electronic devices, is changing how news is delivered and consumed. Technology and digital content for children are rapidly evolving, which will further accelerate the declining need for paper. By the end of 2011, thousands of children’s chapter books will be available online. The books will be much richer and visually appealing than printed versions through their use of video and interactivity. All of these are nascent technologies, so understanding how the market will shift is not clear.

Use of electronic tablets and eReaders is proving that human behavior is changing rapidly and that books, magazines, and newspapers could soon be a story that future genera-

tions will only be able to read about on an electronic device. The developing world is solving their problems their own way by leapfrogging existing technologies and leveraging frugal innovation.

Given the environmental problems caused by papermaking and the predictions that the industry will keep growing in spite of them, being pessimistic from an environmental perspective is reasonable. But big problems require big solutions, and the future looks more optimistic when one understands how innovation can transform industries and societies. Paper is not going to become obsolete anytime in the foreseeable future; however, if individuals and businesses focus on developing new processes and driving innovation, both to reduce the need for paper and make papermaking more sustainable, the problem can be much better managed.

References

- Chaudhari, P. M. *Treatment of paper and pulp mill effluent by coagulation* (Vol. 31(4)). Environmental Technology.
- Combs, C. (2010, October 17). *Will physical books be gone in 5 years?* Retrieved August 12, 2011, from cnn.com: http://articles.cnn.com/2010-10-17/tech/negroponte.ebooks_1_ebooks=nicholas-negroponte-physical-books?s=PM:TECH
- Domtar Corporation. (2010). Retrieved November 10, 2010, from Domtar Corporation: <http://www.domtar.com/en/sustainability>
- Domtar Corporation. (2010). *PaperBecause*. Retrieved november 10, 2010, from Domtar Corporation: <http://www.paperbecause.com/Paper-is-Sustainable/Paper-Truth-or-Fiction>
- Ecology Global Network. (2010). *Ecology Global Network*. Retrieved August 10, 2011, from Ecology Global Network: <http://ecology.com/features/paperchase/>
- eCopy, Inc. (2010). *eCopy, Inc.* Retrieved November 10, 2010, from eCopy, Inc.: <http://www.eCopy.com/Newsroom-eCopy-Names-Second-Fastest-Growing-NH-based-Private-Company.asp>
- Environmental Defense Fund. (2010). *Environmental Defense Fund*. Retrieved August 10, 2011, from edf.org: <http://business.edf.org/paper-waste/improve-your-companys-paper-choices>
- Environmental Energy Technologies Division. (2010). *Environmental Energy Technologies Division*. Retrieved September 24, 2010, from eetd.lbl.gov: <http://eetd.lbl.gov/paper/ideas/html/issues.htm>
- Environmental Paper Network. (2002). *A common vision for transforming the paper industry: Striving for environmental and social sustainability*. Retrieved August 8, 2011, from forests.org <http://www.forestethics.org/downloads/CommonVision.pdf>
- Environmental Paper Network. (2007). *The state of the paper industry: Monitoring the indicators of environmental performance*. Retrieved August 12, 2011, from greenpressinitiative.org <http://www.greenpressinitiative.org/documents/StateOfPaperInd.pdf>
- Environmental Protection Agency. (2010). *Environmental Protection Agency*. Retrieved September 24, 2010, from epa.gov <http://www.epa.gov/tri/stakeholders/datausers/index.htm>
- Environmental Protection Agency. (2010). *Environmental Protection Agency*. Retrieved October 15, 2010, from epa.gov <http://www.epa.gov/osw/consERVE/materials/paper/basics/papermaking.htm>
- Fast Compny. (2010, November 9). *The most wanted 2010 holiday gadgets: Consumer electronics association study*. Retrieved August 12, 2011, from fastcompany.com <http://www.fastcompany.com/1701380>
- Forest Stewardship Council. (2010). *Forest Stewardship Council*. Retrieved October 14, 2010, from fsc.org <http://www.fsc.org/aboutfsc.html>
- Forest Stewardship Council. (2010). *Forest Stewardship Council*. Retrieved October 14, 2010, from fsc.org <http://www.fsc.org/facts-figures.html>

- Forest Stewardship Council. (2010). *Forest Stewardship Council*. Retrieved October 14, 2010, from fsc.org: http://www.fsc.org/pesticides_review.html
- Gates, W. (1999). *Business @ the speed of thought: Using a digital nervous system*. New York, New York, USA: Warner Books.
- Georgia-Pacific. (2010). *Georgia-Pacific*. Retrieved November 10, 2010, from gp.com <http://www.gp.com/aboutus/index.html>
- Georgia-Pacific. (2010). *Georgia-Pacific*. Retrieved November 10, 2010, from gp.com <http://www.gp.com/aboutus/sustainability/forestry/keypractices.html>
- Georgia-Pacific. (2010). *Georgia-Pacific*. Retrieved November 10, 2010, from gp.com <http://www.gp.com/aboutus/sustainability/srr/index.html>
- Georgia-Pacific. (2010). *Georgia-Pacific*. Retrieved November 10, 2010, from gp.com <http://www.gp.com/aboutus/sustainability/srr/popups/definition.html>
- Georgia-Pacific. (2010). *Georgia-Pacific*. Retrieved November 10, 2010, from gp.com <http://www.gp.com/aboutus/sustainability/srr/popups/approach.html>
- Girrbach, C. (2010, March 10). *How Cisco's packaging diet saved \$24 million a year*. Retrieved August 11, 2011, from greenbiz.com <http://www.greenbiz.com/blog/2010/03/10/how-ciscos-packaging-diet-saves-24-million-year>
- Hunter, D. *Papermaking: The history and technique of an ancient craft*. New York, New York, USA: Dover Publications.
- Huhtanen, M. (2010, September 30). *Digital age shreds forest products industry*. Retrieved August 12, 2011, from commercialappeal.com/news-green-no-longer-gold <http://www.commercialappeal.com/news/2010/Sep/30/finns-green-no-longer-gold>
- International Paper. (2010). *International Paper*. Retrieved November 10, 2010, from internationalpaper.com <http://www.internationalpaper.com/US/EN/Company/Sustainability>
- Johnson, S. *Where good ideas come from*. New York, New York, USA: Riverhead.
- Koytoff, V. (2010, October 21). *Strong gains for Amazon's 3rd quarter*. Retrieved August 12, 2011, from newyorktimes.com: http://www.nytimes.com/2010/10/22/technology/22amazon.html?sq=strong_gains_for_amazon's_3rd_quarter&st=cse&adxnni=1&scp=1&adxnnix=1313176776-163pSe2MRoinCd61MPIwg
- Millyard Communications. (2010, August 26). *Business New Hampshire Magazine*. Retrieved August 12, 2011, from <http://www.millyardcommunications.com/index.php?src=news&srctype=detail&category=news&refno=1792>.
- Mims, C. (2010, August 23). *Predicting the death of printing*. Retrieved August 12, 2011, from MIT Technology Review: <http://www.technologyreview.com/blog/mimssbits/25642>
- National Research Council. *Wood in our future: The role of life-cycle analysis*. New York, New York, USA: National Academies Press.

New Hampshire Business Review. (2010). *Questions surround mill purchase*. Retrieved August 12, 2011, from nhbr.com <http://www.nhbr.com/businessnewsstatenews/898574-257/questions-surround-mill-purchase.html>

Nokia Corporation. (2010). *Nokia Corporation*. Retrieved August 12, 2011, from nokia.com <http://www.nokia.com/about-nokia/company/story-of-nokia>

Nuance Communications, Inc. (2010, October 5). *Nuance Communications*. Retrieved August 12, 2011, from nuance.com: http://www.nuance.com/news/pressreleases/2009/20091005_ecopy.asp

Omtool, Ltd. (2010, August 25). *Omtool*. Retrieved August 12, 2011, from omtool.com: <http://www.omtool.com/company/newsArticle.dfm?aid=176>

Omtool, Ltd. (2006, April 17). *Omtool, Ltd.* Retrieved August 12, 2011, from omtool.com <http://www.omtool.com/company/newsArticle.cfm?aid=108>

One Laptop per Child. (2010). *One Laptop per Child*. Retrieved August 11, 2011, from laptop.org <http://laptop.org/en/laptop/index.shtml>

Ridley, m. *The rational optimist*. New York, New York, Usa: Harper Collins.

Scientific Applications International Corporation. (2006, May). *Life cycle assessment: Principles and practice*. Retrieved August 12, 2011, from epa.gov: <http://www.epa.gov/nrmrl/lcaccess/pdfs/600r06060.pdf>

Tam, P. (2004, September 13). The paper trail: Cost cutters have their sights on a new target: the office printer. *The Wall Street Journal*, p. R4.

The Economist. (2010, September 30). *Chasing king apple*. Retrieved August 8, 2011, from economist.com <http://www.economist.com/node/17151127>

The Economist. (2010). *Energy in the developing world*. Retrieved November 10, 2010, from economist.com: <http://www.economist.com/node/16909923>

The Economist. (2010, March 31). *E-publish or perish*. Retrieved August 10, 2011, from economist.com <http://www.economist.com/node/15819008>

The Economist. (2010, October 5). *Learning to e-read*. Retrieved August 12, 2011, from economist.com <http://www.economist.com/node/386160>

The Economist. (2010, September 2). *Ruses to cut printing costs*. Retrieved August 12, 2011, from economist.com: <http://www.economist.com/node/16910041>

The Economist. (2009, December 30). *The apparatgeist calls*. Retrieved August 12, 2011, from economist.com: <http://www.economist.com/node/15172850>

The Economist. (2010, September 2). Dadri, Uttar, *The next billion geeks*. Retrieved August 12, 2011, from economist.com: <http://www.economist.com/node/16944020>

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The Economist. (2010, June 10). *The strange survival of ink*. Retrieved August 12, 2011, from economist.com: <http://www.economist.com/node/16322554>

Trachtenberg, J. (2010, October 25). B&N aims e-books at kids. *The Wall Street Journal* , p. B4.

US Fish and Wildlife Services. (2010). *Affected Environment*. Retrieved August 12, 2011, from fws.gov http://www.fws.gov/Northeast/planning/Missisquoi/draftCCP/03_CHAPTER_3.pdf

Wargo, J. *Green intelligence: Creating environments that protect human health*. New Haven, Connecticut, USA: Yale University Press.

Will physical books be gone in 5 years? (2010, October 20). CNN. Retrieved from http://articles.cnn.com/2010-10-17/tech/negroponete.ebooks_1_e-books-nicholas-negroponete-physical-books?s=PM:TECH

World Resources Institute. (2010). *World Resources Insitute*. Retrieved from earthtrends.wri.org http://earthtrends.wri.org/searchable_db/index.php?theme=9&variable_ID=573&action=select_countries

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APPENDIX A

Common Chemicals Used in Forestry

Summary of the Common Chemicals Used in Forestry and Their Toxicity and Environmental Fate											
Main active ingredient	Type of chemical	Other hazardous ingredients	TOXICITY				Carcinogenic activity	ENVIRONMENTAL FATE			
			Inhalation	Ingestion	Absorption: skin and/or eyes	Chronic exposure		Soil	Half-life	Water	Nontarget organisms
Glyphosate	Broad-spectrum herbicide	POEA-surfactant	Moderate toxicity	Generally nontoxic	Skin and eye irritant	Could cause damage to kidney and liver	Class C*	Moderately persistent	47 days in soil 12 days to 10 weeks in water	Risk of ground water contamination	Moderately toxic to fish
Hexazinone	Broad-spectrum herbicide	Ethanol in Velpar-L	Moderate toxicity	Acute toxicity	Moderate toxicity, severe eye irritant	No chronic risk assessment	Class D*	Mobile and persistent	90 days	Health advisory of 200 ppb	Highly toxic to algae
Triclopyr	Broad-spectrum herbicide	Diesel fuel carrier	Corrosive irritant	Corrosive irritant	Corrosive irritant	*No chronic risk assessment is required* ¹	Class D*	Soil sterilant	46 days	Risk of ground water contamination	Some risk to nontarget organisms
Imazapyr	Broad-spectrum herbicide	Surfactant	Corrosive irritant	Ulcers, lesions	Corrosive irritant	Neurotoxin	Some carcinomas observed, brain tumors	Mobile and persistent	Residual activity: 6-12 mo. in humid temperate zone	Risk of ground water contamination	Not enough evidence
Sulfmeturon-Methyl	Broad-spectrum herbicide	Surfactant	Slightly toxic	Slightly toxic	Corrosive irritant	Increased liver weight, anemia	No observed activity	Soil sterilant	20-28 days	No evidence of contamination	Slightly toxic to fish
MetSulfuron-Methyl	Broad-spectrum herbicide	Sodium naphthalene	Low acute toxicity	Systemic poisoning if a lot is consumed	Corrosive irritant	Jaundice, anemia	No evidence	Highly mobile	14 to 180 days	Risk of ground water contamination	Practically nontoxic to fish
Diammonium Phosphate	Fertilizer for phosphorus	Ammonia & iron compounds	Results in severe burns to lungs	Burns to throat, mouth	Burns to eyes and skin	Blindness, lung disease, liver cirrhosis, fluorosis	No evidence	Taken up as a nutrient by plants	n/a	Risk of ground water contamination	Slightly toxic to fish and invertebrates
Urea	Fertilizer supplement for nitrogen	n/a	Irritation, severe cough	Irritation, nausea, vomiting	Corrosive irritant	Protein metabolism disruption, emphysema	No evidence	Mobile and persistent	140 days	Risk of ground water contamination	No information found