Harnessing Catastrophe to Promote Resource Recovery and Eco-industrial Development

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Keywords:

adaptation
debris management
Hurricane Katrina
industrial ecology
recycling
waste management

Summary

Hurricane Katrina devastated New Orleans, Louisiana, USA, causing widespread damage to industry, housing, and infrastructure. The area of New Orleans East was particularly devastated, including a cluster of industries, such as a major food-processing plant, manufacturing facilities, and bulk material and gas processors. Although this area was well suited for resource recovery and eco-industrial linkages, little progress has been made in implementation. This article explores New Orleans as a case study in the application of industrial ecology to disaster management. Hurricane Katrina's damage to New Orleans resulted in a significant increase in the amount of waste flowing into New Orleans East, which precipitated a massive expenditure of federal funds toward debris management. Those circumstances created an unprecedented opportunity to capitalize a resource recovery program and to establish eco-industrial relationships, both of which would have resulted in new jobs and environmental improvement. Yet straightforward opportunities for resource recovery and eco-industrial linkage were overlooked or dismissed, in spite of antilandfill activism from the environmental community and formal recommendations for recycling from scientists and other professionals. We describe the specific resource recovery and eco-industrial opportunities that were available to New Orleans East, especially those that were magnified by Hurricane Katrina, and analyze the barriers that prevented their actualization. We also provide recommendations for overcoming barriers to resource recovery and eco-industrial progress with the goal that future postcatastrophe scenarios may benefit from more effective use of relief and recovery funding.

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DOI: 10.1111/j.1530-9290.2009.00136.x

Volume 13, Number 4

Introduction

Disasters often present opportunities to increase a region's recycling activity and advance eco-industrial development[1] by creating secondary materials. Disasters, which may include earthquakes, hurricanes, tsunamis, and war, can be characterized as events that "overwhelm local capacity, necessitating a request to the national or international level for external assistance" (Centre for Research on the Epidemiology of Disasters 2008). As mounting evidence suggests that the frequency of disasters will increase with oncoming climate change (e.g., Hoyos et al. 2006), effective disaster management will be a greater priority for society. Disasters have become increasingly costly: Over the past 3 decades, global costs of weather-related disasters have increased from US$8.9 billion to US$45.1 billion (Bouwer et al. 2007). A significant portion of this cost is spent on recovery and reconstruction, including debris management, which commences immediately following the disaster and continues during longer term reconstruction (Pike 2007).

The first phase of debris management is dedicated to immediate disaster relief, focused on removing debris from access routes to accommodate emergency vehicles and debris haulers. Expeditious removal of debris is also undertaken from residential and commercial areas before the organic fraction can decompose to harbor pests and create human health risks. The U.S. federal government provides funding for this phase in accordance with the Robert T. Stafford Disaster Relief and Emergency Assistance Act (42 U.S.C. §§ 5121–5206; C.F.R. §§ 206.31–206.48). Those funds are allocated by the U.S. Federal Emergency Management Agency (FEMA) and managed by the U.S. Army Corps of Engineers (COE). Approximately 55% of all federal disaster spending is directed toward immediate relief, including Phase 1 debris removal (Pike 2007).

The second phase of debris management is the long-term removal of debris, which assists reconstruction. The common practice of disposing of material in landfills during this phase often impedes sustainable development and perpetuates a disaster's economic and environmental damage (Baycan and Petersen 2003). Although opportunities for debris diversion and recycling are limited throughout the immediate aftermath of a disaster (Solid Waste Association of America 2005), later phases of disaster recovery present enhanced prospects for material reuse. By focusing long-term debris planning and spending on the broader goals of ecological and economic sustainability, officials can improve the region's resilience to future disasters (Blakely 2007). The expansion of recycling capabilities and eco-industrial planning (e.g., matchmaking adjacent industries around shared or exchanged resources) results in job creation and fosters a more diversified web of enterprises to facilitate rapid and efficient recovery from future disasters (Deutz and Gibbs 2004).

Here, we use Hurricane Katrina and New Orleans, Louisiana, as a case study to examine debris management and opportunities for eco-industrial development. Our objective is to analyze the specific barriers that impeded effective debris management following Hurricane Katrina and to recommend how those barriers may be overcome in future disaster recoveries. First, we describe Katrina's impacts and review responses to similar catastrophes. We then explore why post-Katrina recovery and reconstruction efforts failed to advance an eco-industrial network of resource sharing and materials exchange, despite evidence that the region is well suited for such.[2] Our analysis focuses on New Orleans East, an industrialized corner of the metro area with several landfills and large facilities producing bulk materials, manufactured products, and food goods. With the goal of improving preparation for future disasters, we conclude our analysis with recommendations to overcome barriers that hindered effective debris management and eco-industrial development in New Orleans. More than 3 years after the disaster, debris management failures continue to impact the environmental health of the citizens of New Orleans (GAO 2008).

Hurricane Katrina

On August 29, 2005, Hurricane Katrina made landfall in the Gulf Coast region of the United States and generated the greatest recorded amount of disaster-related debris in U.S. history (GAO 2008). For example, 36 million pounds (16 million kilograms) of rotten meat and other perishable items were removed from commercial storage facilities in New Orleans (Luther 2006). Overall, Hurricane Katrina generated 22 million tons[3] of debris across the Gulf Coast states, with 75% occurring in Louisiana (Louisiana Department of Environmental Quality 2006). An estimated 100 million cubic yards (76.5 million cubic meters) of additional disaster debris are expected to be generated in New Orleans as part of demolition and renovation (Luther 2006).

Anticipating an insurmountable economic burden to the local economy, the federal government agreed to reimburse Louisiana for 100% of the cost of debris removal, as opposed to the usual 80% (FEMA 2005). The vast majority of federal funding was dedicated toward the collection and disposal of debris in local landfills, some of which had been closed for safety reasons (Subra 2007). From an eco-industrial perspective, landfills are at the bottom of the waste management hierarchy, below source reduction, reuse, and recycling (United Nations Environment Program 2005). Although landfilling might have been warranted immediately following the disaster, the continued use of landfills throughout the reconstruction period exacerbated environmental hazards (e.g., lack of landfill cover, methane generation, and ground water contamination). Those hazards are especially relevant in New Orleans due to the shallow water table, frequency of flooding, and scarcity of cover materials (Colten 2001).

Precedents for Effective Debris Management in Responses to Other Disasters

Louisiana's Hurricane Katrina recovery effort failed to incorporate lessons learned from past disasters and debris management efforts. Following the Northridge Earthquake in 1994, the city of Los Angeles, California, did not have a predisaster debris management plan, and debris was initially directed to three landfills. In collaboration with FEMA, however, supervising officials quickly developed and implemented a recycling program with the capacity to recycle 50% of the earthquake debris collected weekly, which totaled over 1.5 million tons (EPA 1995). The recycled debris was used for reconstruction: crushed concrete and asphalt for roads; ground brick for baseball fields; dirt for landfill cover; and woody debris for landscaping, fuel cogeneration, and compost. Metal was also salvaged and recycled (EPA 1995). A year after the disaster, Los Angeles had established 18 recycling facilities and reduced the total number of landfills from three to one.

Hurricane Iniki struck the Hawaiian island of Kauai in September 1992, creating 5 million cubic yards of debris, the equivalent of 7 years' worth of waste under normal circumstances (EPA 1995). Within 3 months, recovery officials had developed a debris management plan emphasizing recycling, starting with separation and sorting at the site of generation. Residents were mandated to separate storm-generated and household debris into green waste, metals and appliances, wood debris, aggregate materials, and mixed debris. All metals, appliances, tires, and aggregate materials collected from residents were reused. Aggregate was used to construct revetment walls to stabilize coastal property, and more than half of the 100,000 tons of total green waste created by the storm was composted (EPA 1995).

In 1999, the Marmara earthquake in Turkey generated 13 million tons of debris in a highly industrialized area (Esina and Cosgun 2006). Officials presiding over the relief efforts immediately developed a rubble management plan in concert with the United Nations Development Program, which called for source reduction and sorting at the point of collection, followed by reuse, recycling, and disposal (see figure 1).

In accordance with the plan, a stationary recycling plant was established to process the postdisaster debris stream. The plant was damaged by reinforcement bars commingled with the construction and demolition debris. Waste that could not be recycled was landfilled at sites approved by the Ministry of the Environment.

Armed conflicts in Herzegovina and Beirut also serve as useful examples of the implementation of effective debris management. Following 4 years of conflict in Mostar, Herzegovina, more than 1,000 buildings needed to be demolished, which created 200,000 tons of construction and demolition (C&D) waste (Calòa and Parise 2009). The Danish Ministry of Foreign Affairs financed the development and execution of a debris management program that prioritized the recycling and reuse of construction waste,

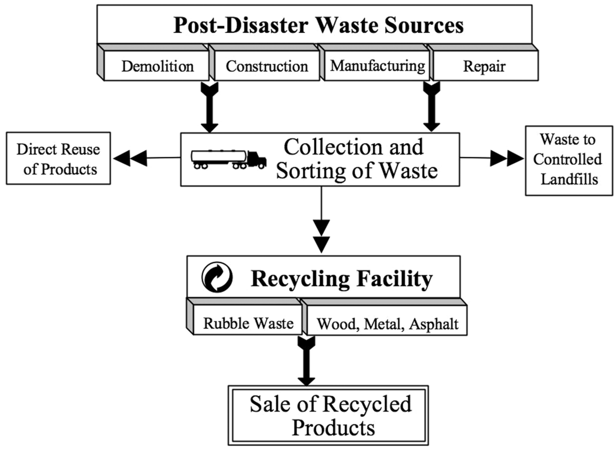

Figure 1 An example of optimal process flows of waste following a disaster. *Source*: Government of Turkey Rubble Plan See Esina and Cosgun (2006).

including the use of asphalt and cement for roads and concrete for new building foundations. The more than 4 million tons of demolition waste that were generated in postconflict Beirut prompted the development of a recycling facility similar to the one that processed debris from the Marmara earthquake (Lauritzen 1998). As in Turkey, materials also damaged the Beirut facility. The disaster waste management experiences in Turkey and Beirut highlight the importance of sorting debris into recyclables and nonrecyclables prior to processing to ensure effective and efficient recycling programs (Baycan and Petersen 2003).

These examples demonstrate that disaster-generated debris can be recycled and used for reconstruction and illustrate how relief funding may be harnessed for developing permanent eco-industrial infrastructure. Those outcomes are best realized when an adaptive debris management plan is in place prior to the disaster. In the examples above, however, debris management plans were developed post hoc following catastrophes, which resulted in some delays and difficulties, such as equipment damage. When communities prepare debris management plans prior to disaster, the urgent phase of immediate disaster relief yields a larger fraction of materials for reuse.

Pre-Hurricane Katrina Opportunities for Resource Recovery and Eco-industrial Development

Although a small fraction of the municipal waste stream was intercepted in a curbside recycling program prior to Katrina, New Orleans East received the majority of waste generated in the City of New Orleans and the broader area. Waste streams included municipal solid waste (MSW), C&D waste, and vegetative debris. Most of these materials were buried in landfills near New Orleans East, although some materials were consolidated at transfer stations and relayed eastward to landfills in Mississippi. A considerable portion of the pre-Hurricane Katrina waste stream was organic and thus readily compostable or convertible into energy.[4]

New Orleans East hosts an industrial sector that includes a coffee roasting facility, a cement factory, an industrial gas processor, and a major aerospace assembly facility. Although the coffee facility generated large amounts of organic waste (25 tons of chaff and spent grounds per day), the amount of waste generated within New Orleans East was relatively small compared to that from greater New Orleans. None of this local organic waste stream was recovered.[5] A few small-scale, downstream recycling operations operated in New Orleans East, however, including a facility that sorted and crushed concrete into aggregate, an employee-run recycling program at the aerospace facility, and an organic composting facility that received waste from a local horse-racing track and a local power company's tree-trimming program (Rowland 2008). A composting facility had operated for several years but closed abruptly approximately a year before Hurricane Katrina (Rubin et al. 2005).

Prior to and following Katrina, the organic waste streams of New Orleans East and the

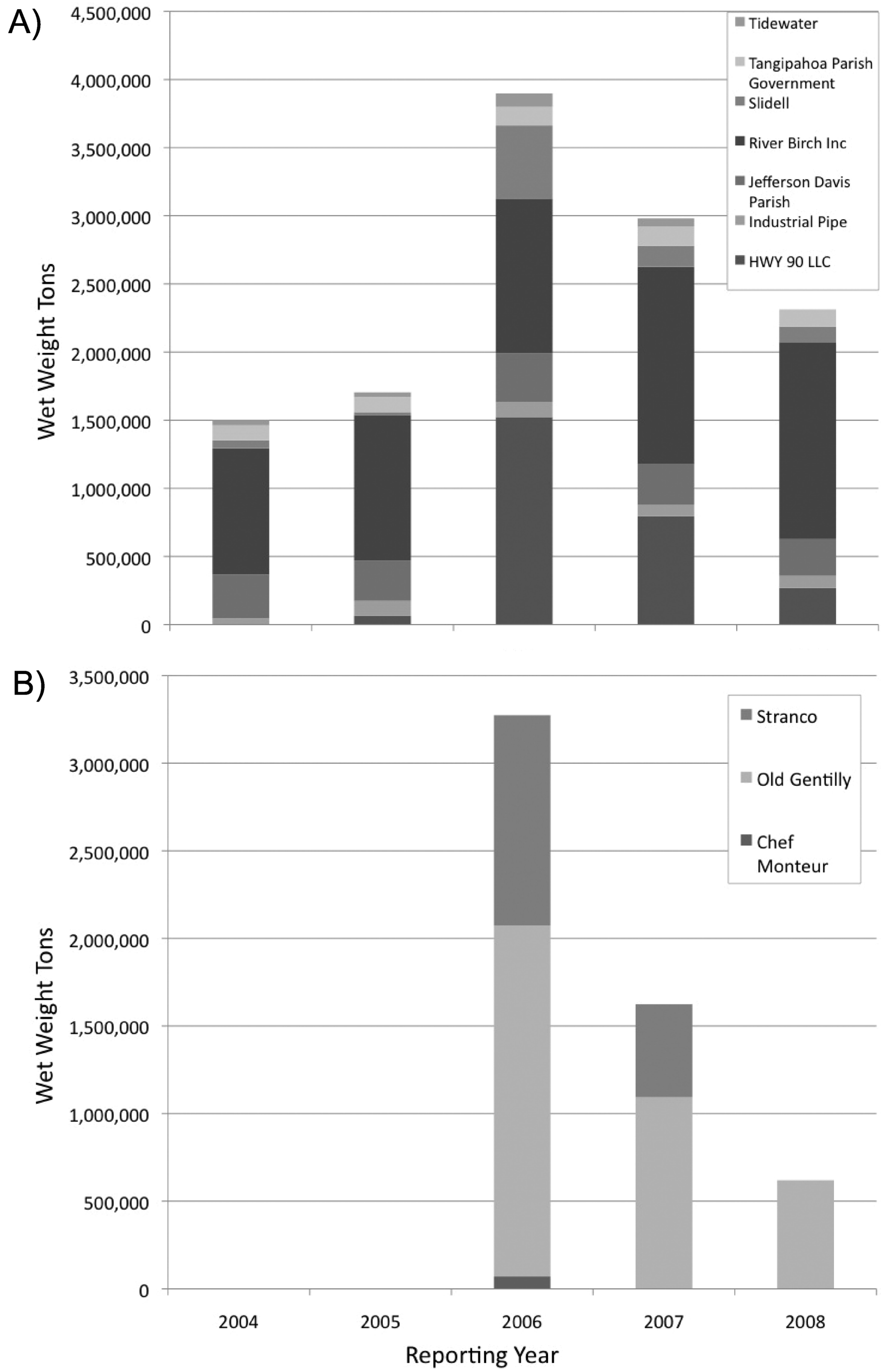

Figure 2 Nonindustrial waste reported in landfills servicing areas impacted by Hurricane Katrina for reporting years 2004–2008. A reporting year is from July to June, with Hurricane Katrina occurring in reporting year 2006. (A) Landfills that were open prior to Hurricane Katrina. (B) Emergency landfills opened in response to Hurricane Katrina. No data are reported for Tidewater Landfill in 2008 and Highway 90 in 2004. Data are from Louisiana Department of Environmental Quality (1998).

greater New Orleans area offered a number of eco-industrial opportunities, including

- segregation and crushing of aggregate and glass for cement, fill, and coastal restoration;
- composting of organics for wetlands restoration and local farming, along with landscaping opportunities for local residents, industrial facilities, and a newly built amusement park;
- processing of organic waste into fuel for combustion-based power generation;
- anaerobic digestion of putrescent organic waste to provide biogas; and
- collection and processing of waste vegetable oil into biodiesel for use by transporters and a back-up diesel generator at the aerospace facility.

A major barrier to capitalizing on these eco-industrial opportunities was lack of funds to acquire technology and equipment, such as chippers and windrow turners for organic waste, crushers for aggregate and glass, anaerobic digesters for putrescent waste, and process vessels for converting waste vegetable oil into biodiesel. The lack of a state renewable energy portfolio standard also played a role, as a market for renewable energy credits would have incentivized eco-industrial opportunities.

Post-Katrina Opportunities for Resource Recovery and Eco-industrial Development

Hurricane Katrina generated large volumes of nonindustrial waste within the eight parishes the make up the New Orleans metropolitan area (see figure 2). The year following Hurricane Katrina, C&D waste streams increased by more than 2,000%, whereas the overall nonindustrial waste stream increased by 320%.[6] Nonindustrial waste declined in 2007 and 2008, although it has remained elevated since the disaster (see figure 2). Five emergency landfills were opened in response to Hurricane Katrina, four of which accepted 100% C&D waste.[7] The operation of the additional C&D landfills resulted in widespread opposition from the surrounding community due to the environmental hazards that persist from depositing disaster debris in unlined C&D landfills (Pardue 2006). Two of the landfills, Old Gentilly and Chef Menteur, have also been contested on environmental justice grounds, due to their proximity to low-income, minority communities (Citizens for a Strong New Orleans East 2006). The Old Gentilly landfill, constructed on top of a former MSW landfill, was reopened following Hurricane Katrina after being closed in 1986. Opened in April 2006, the Chef Menteur landfill was closed in August of the same year, following ardent opposition from environmental and community groups, including the Louisiana Environmental Action Network and Citizens for a Strong New Orleans East (GAO 2008). Chef Menteur is awaiting a COE permit under section 404 of the Clean Water Act to complete the closure process.[8]

When Hurricane Katrina devastated whole sections of New Orleans, it became increasingly apparent that a major rebuild would be required. Local communities anticipated that large amounts of federal funding would be committed to the recovery effort. Viewing the situation as a tabula rasa, dozens of organizations—both incumbent and external—proposed plans on diverse topics, such as urban layout, building codes, energy and water infrastructure, transportation, and education. Both the city and the state established committees to harvest local input on how the recovery might be best managed to ensure long-term community improvement. Those committees received input from both local and external sources and issued various reports and recommendations. The waste-management and recycling community was perhaps the first to offer a specific plan to guide the recovery, providing technical and logistic details on how to sort debris, return materials back to the city, and leverage funding to create local jobs and purchase equipment for permanent recycling programs (C. Reith, 2005, People, Planet, and Prosperity Project, unpublished data). Despite input from academia, environmental organizations, and local communities, eco-industrial planning and implementation were suppressed by the urgency of the post-Hurricane Katrina recovery efforts.

Postdisaster Opportunities for Eco-industrial Planning in New Orleans East

As buildings continue to be demolished and debris landfilled 3 years following Hurricane Katrina, opportunities to promote eco-industrial development remain. FEMA estimated in July 2008 that federal funding had been allocated for 16,900 home demolitions and that 6,100 had yet to be demolished around the New Orleans area (GAO 2008). As long-term reconstruction moves forward, New Orleans lacks citywide programs for recycling and for the sorting and reuse of C&D waste.

Given the large influx of waste and debris, combined with New Orleans East's densely packed industrial, commercial, and agriculture activities, eco-industrial possibilities are numerous. To take advantage of these possibilities, the city must establish a debris management plan that incorporates eco-industrial principles and then support that plan with funding. We briefly describe three opportunities that could be effective and economically sustainable.

Organic Material: An Abundant and Valuable Resource

The reuse of organic debris provides a solution to one challenge of effective debris management immediately following a disaster. Composting and redistribution of organic debris were accommodated only in a few localized instances after Hurricane Katrina in New Orleans (Etheredge 2007). The large volumes of post-Hurricane Katrina MSW and C&D waste contained organic material (albeit commingled with other matter), including millions of cubic yards of vegetative matter. Numerous government and nonprofit organizations recommended a program to maximize the use of this organic debris fraction.[9] For example, organic materials can be used for various aspects of wetland restoration (Middleton 1999). Instead of being recycled, the vast majority of the organic debris was uniformly shredded into wood chips, as prescribed by the U.S. Environmental Protection Agency (EPA 1995) and discarded in landfills or combusted in air-curtain incinerators.

Several arguments were mounted against composting on the grounds that compost would propagate Formosan termites and that toxic constituents from nonvegetative debris would contaminate organic compost material. Quarantine on the movement of cellulose products from parishes where Formosan termites were present did complicate wood chipping and composting of vegetative debris. When properly managed, however, thermal composting destroys termite larvae and thermally denatures toxins (Hu and Appel 2004). In hindsight, landfilling of organic material after Hurricane Katrina was a missed opportunity to recover the resource value of waste.

Recycling Opportunities for the Inorganic Fraction

Many inorganic materials flowing into New Orleans East immediately following Hurricane Katrina and during the long-term recovery period were conducive to recycling. Examples of reusable materials include (1) concrete rubble for construction, including materials for foundations, roads, and levees; (2) asphalt for roofing or pavement; (3) metals (e.g., rebar, pipe, and flashing) for commercial scrap recycling; and (4) ground glass for beach materials, pavement additive, or feedstock for more glass.

Before waste and debris can be recycled, they must be sorted into recyclables and nonrecyclables, and doing so is often a necessary condition for the profitability of operations (Baycan and Petersen 2003). During the immediate aftermath of Hurricane Katrina, the economic attractiveness of recycling a given class of waste or debris was diminished, as material was mixed in with the overall amalgam being collected and transported. The upstream failure to sort waste and debris during the collection not only made it difficult to offset collection costs with revenues from recycling inorganic matter but also deprived the reconstruction of locally available secondary materials.

Plasma Gasification: A Long-Term Strategy for Creating Value From Unsorted Materials

An integrated gasification combined-cycle waste-to-energy plant has been proposed for unsorted materials in New Orleans East. The facility is envisioned as a potential centerpiece for the long-term postdisaster industrial system. A plasma gasification facility processes shredded, unsorted waste into syngas, used to generate electricity, and inert solids for beneficial reuse (Vaidyanathana et al. 2007). The plasma gasification facility operates at high temperatures to avoid the generation of dangerous emissions associated with combustion-based incinerators (Miller and Lemieux 2007). Plasma gasification of MSW and automobile shredder residue has been successful on a relatively large scale in Japan, whereas plasma gasification has been used on a smaller scale to treat hazardous waste in Canada and Europe (Dicus 2004).

Waste inputs and energy outputs of such plants vary considerably; the order of magnitude proposed for New Orleans East is 2,500 tons day^{-1} to produce 138 mega-watts of electricity (K. Ardani, 2008, Sun Energy Group Project, unpublished data). For every 10 tons of waste, 1 ton of inert solids is produced that can be used for construction applications, including levees. Plasma gasification technology can also process waste mined from existing landfills (Rathje 1991). This capability may prove important in post-Hurricane Katrina New Orleans, because many landfills are not environmentally stable and the majority of post-Hurricane Katrina waste has already been deposited in landfills.

Plasma gasification facilities are a potential long-term strategy for debris management in New Orleans. Such a large project, however, cannot be quickly established in response to disasters because of long permitting and construction processes, along with complex financing and market considerations, such as guaranteed supplies of wastes and markets for electricity. This complicated process has not discouraged entrepreneurs, however, several of whom were in the early phases of moving forward in 2008 with a plasma gasification facility in New Orleans.

Understanding and Overcoming Barriers to Eco-industrial Development

New Orleans has been unsuccessful in advancing effective debris management despite enormous potential to recycle materials, build permanent infrastructure, and promote eco-industrial linkages. What were the barriers to resource recovery, and how might they be overcome with strategic planning and policies?

A number of barriers contributed to specific missed opportunities, all of which are likely surmountable (see table 1). First, an urgent need to clear streets of debris led to hasty commingling of materials, which complicates and inhibits effective recycling programs. Second, Louisiana's debris management plan included provisions for eco-industrial development, such as recycling and cogeneration of energy, but provided scarce support to local governments in the execution of those provisions. Third, the initial sense of urgency was inappropriately extended beyond the crisis phase of the recovery, which created inertia that suppressed the local government's capacity to properly formulate a citywide recycling and debris management plan. Finally, the federal contracting protocols provided perverse incentives that rewarded landfilling.

The New Orleans long-term rebuilding effort was likely impeded by the failure to sort staged materials throughout the immediate disaster relief phase of the debris management program. Immediate debris management efforts included 343 large staging sites around the metropolitan area; those sites failed to separate recyclable materials suitable for use in reconstruction efforts (March and Wiley 2007). As large volumes of unsorted material rapidly accumulated at each staging site, the COE was forced to relocate staged material to landfills to accommodate newly arriving debris. Under pressure from the urgency of the disaster, officials established a "stage and landfill" protocol for debris management. Even once public safety emergencies had stabilized and the immediate sense of urgency had subsided, government agencies perceived alternative methods of disposal as technically and economically infeasible.

In August 2006, Louisiana formally acknowledged the pressing need for recycling in a newly mandated state debris management plan. A lack of recycling prompted State Senator Clo Fontenot to introduce Senate Bill 583, signed into law as Act 662, which mandated that the Louisiana Department of Environmental Quality (LDEQ) develop a statewide debris management plan that incorporated recycling, composting,

Table 1 Some opportunities, barriers, and remedies in postdisaster resource recovery in New Orleans following Hurricane Katrina.

General opportunity	*New Orleans opportunity*	*Barrier*	*Remedy*
Deconstructing	Creating quality jobs to deconstruct ruined homes and recycle salvaged materials for reuse	Requirements for removing ruined structures within 1 year and inadequate resources to deconstruct	Immediate postdisaster funding of existing deconstruction resources to hire and train workers, purchase capital equipment, and establish clearinghouses
Recycling botanical debris	Returning all organics to restore urban ecology and rebuild wetlands	Directives mandating transport of botanical debris from processing sites to landfills or air curtain incinerators	Designation of operating areas for processing of botanical debris into compost and other useful materials and transport back to needy areas
Sorting and recycling nonbotanical debris	Segregating debris and processing (e.g., magnetic sorting, composting) and using these materials in rebuilding	Lack of capital equipment or operating space to recycle, which resulted in all materials being landfilled	Identify needs for space and capital equipment for debris management before disaster, and develop spending plans to initiate recycling as quickly as possible
Establishing permanent recycling infrastructure	Purchasing equipment and establishing disaster management operations that would become permanent after the recovery	All funds were spent on services and contractor-owned equipment that does not remain after the recovery	Quantify needs and identify space for a permanent recycling center before a disaster, and earmark part of recovery spending toward permanent recycling
Producing renewable energy from waste	Establishing facility that processes high-BTU debris and waste into renewable energy	Lack of ensured access to waste stream for tipping fees and grid for electricity sales	Develop draft contract mechanisms to enable officials to quickly negotiate debris relationships with potential developer, and provide for guaranteed grid access facilitated by a Renewable Portfolio Standard
Enhancing eco-industrial networks to improve regional eco-efficiency	Convening all partners in planning session with possible funding to promote waste and resource exchanges (e.g., coffee and biodiesel)	Lack of concerted effort to coordinate redevelopment activities to realize eco-industrial improvement	Develop regional eco-industrial plan and include expedited implementation scenario in the event of disaster and recovery spending

Note: The order of opportunities does not imply prioritization. BTU = British thermal unit.

waste volume reduction, and cogeneration of heat and electricity. Act 662 also stipulated that vegetative debris be used for coastal restoration projects and that landfilling of vegetative debris not be considered the optimal choice of deposition. Although the state debris management plan promotes eco-industrial development, it provides no enforceable mandate or financial support to local governments. New Orleans is responsible for identifying sites where recycling and beneficial reuse may be implemented, and it also must fund standby contracts that "provide for the oversight, implementation, and operation of recycling and beneficial re-use projects associated with disaster generated debris activities" (Louisiana Department of Environmental Quality 2006, 3). Although it is impractical for the state to fund all beneficial reuse programs at the local level, New Orleans would benefit from enhanced integration of the state and city expectations for debris management and disaster planning. The state plan would have been more successful in advancing effective debris management had it provided explicit guidance on how to plan and implement recycling programs at the local level and leverage recovery spending toward that goal.

The third barrier to effective debris management and eco-industrial progress in New Orleans was the continuation of LDEQ's emergency order, which remained in place 3 years after Katrina. In August 2005, LDEQ issued a Declaration of Emergency and Administrative Order to guide debris removal efforts in New Orleans. As the city continued to be inundated by debris, LDEQ officials amended the emergency order in November 2005 to expand the definition of C&D debris to include potentially hazardous materials, such as demolition debris containing treated wood, carpeting, Sheetrock, and asbestos.[10] This expansion allowed haulers to deposit materials in C&D landfills that would otherwise be subject to more stringent environmental regulations. The emergency order was extended until August 29, 2008. The unnecessary extension of the crisis phase of the recovery efforts has created inertia that continues to compromise the local government's capability to properly formulate citywide plans for recycling and debris management.

The final barrier centers on perverse incentives to deposit debris in landfills (Waxman 2006). The COE negotiated four debris-hauling contracts worth \$500 million each. The contracting strategy called for collection-and-hauling firms to be paid on the basis of the weight of materials delivered to staging areas and landfills. The four firms competed aggressively for materials within their assigned districts. Collectors were not rigorous in keeping household hazardous waste out of the collection stream, despite being trained and mandated to do so. Moreover, contractors fraudulently mixed vegetative debris with C&D debris to increase revenues (Waxman 2006). The fast pace of collection and financial incentive to maximize the amount of material hauled to staging areas and landfills complicated and discouraged recycling efforts. In the lucrative post-Katrina situation, contract haulers and landfill operators jointly lobbied against resource recovery initiatives that were contrary to their interests (Waxman 2006).

Recommendations and Conclusion

The case of Hurricane Katrina and New Orleans illustrates common barriers to effective debris management and eco-industrial development. A plan to overcome those barriers must address deconstruction, segregation and sorting, establishment of permanent recycling infrastructure, and enhancement of eco-industrial networks through strategic planning. Elements of such a plan would include

- community input in the process of preselecting sites to stage and sort debris;
- identification of prospective debris-management staging areas and engagement of stakeholders in their planning;
- establishment of a hierarchy of debris-management options that favors source reduction, reuse, and recycling over landfilling;
- identification of material-processing options, including potential equipment needs, throughput rates, and operating costs;
- identification of local resources (e.g., equipment and expertise), along with

budget requirements to mobilize those resources;

- characterization of current and potential resource recovery opportunities, including eco-industrial linkages and planning to leverage recovery spending toward realizing those opportunities;
- preparation of business plans and establishment of commercial relationships for resource recovery activities;
- development of emergency-activated protocols for mobilizing resources, engaging stakeholders, and implementing resource recovery programs; and
- creation of increased institutional capacity through enhanced coordination amongst all levels of government.

Planning should be region-specific, although prompted and guided by experiences and expertise elsewhere. Although funding would be necessary for preparing regional plans and creating institutional capacity, those expenditures would likely be recovered many times over by the savings on postdisaster debris management spending. Ultimately, the spending toward planning would be rewarded by the heightened long-term economic and environmental benefits of reduced landfilling, increased resource recovery, and establishment of industrial symbiosis in disaster-affected regions.

Disasters represent opportunities to implement resource recovery and eco-industrial programs that might not be affordable prior to the disaster. The volumes of potentially reusable debris and funding for relief and recovery provide ample opportunity to purchase capital equipment for short-term processing and permanent recycling. Related to this is the opportunity to establish or enhance eco-industrial linkages. New Orleans East represented a fertile opportunity to convert a mixed-used area with many waste streams into a model of resource recovery and eco-industrial linkage, all funded by the disaster-recovery spending in response to Hurricane Katrina. Unfortunately, the majority of opportunities for improvement were not realized due to a number of barriers (see table 1).

From the perspective of industrial ecology, the most important barrier to an efficient and effective recovery for New Orleans was the lack of a city debris management plan that built on previous lessons learned from past disasters. An a priori debris management plan would have allocated funding toward capitalization of recycling equipment and enhancement of other eco-industrial opportunities, guided in part by local experts. In industrial ecology as well as other areas of sustainable development, disasters may be harnessed to affect permanent improvement, but planning and strategic spending are required.

Acknowledgements

The pre-Katrina portion of this study was funded by the U.S. Environmental Protection Agency's People, Planet, and Prosperity Program. Jackie Rubin and Madeline Pryor made important contributions to the study and the ideas that were carried forward to this article. We are grateful to Marty Rowland, Robert Thomas, and John Sullivan for their comments and discussions and to Heidi Woehrle for her assistance with figures. Funding for C. Josh Donlan was provided by the Alcoa Foundation, Resources for the Future, and Cornell University. We thank the three anonymous reviewers whose comments improved this article.

Notes

1. Eco-industrial relationships are defined here as relationships in which businesses cooperate amongst themselves and with the local community in an attempt to reduce waste and pollution, share resources, and work toward sustainable enterprises and development.
2. A team led by Charles C. Reith had analyzed and characterized New Orleans East relative to its eco-industrial potential before Katrina under a grant provided by the U.S. Environmental Protection Agency's People, Planet, and Prosperity Program.
3. All tons in this article are short tons. One short ton $\approx$ .907 megagrams (Mg) = .907 metric tons.
4. An estimated 64.9% of the pre-Katrina MSW stream from Metro New Orleans consisted of organic waste (EPA 2006). Pre-Hurricane Katrina C&D streams also contained organic wastes, estimated between 117,327 and 239,987 tons per year (Louisiana Department of Environmental Quality 1998).
5. The coffee roaster had at one time burned some of its organic waste stream for process heat,

until the Louisiana Department of Environmental Quality (LDEQ), for reasons related to air quality, prohibited this practice (Mayeaux 2006).

6. C&D waste is defined by the U.S. Environmental Protection Agency as waste generated by building, remodeling, or demolition activities and may include such wastes as wood, wood products, concrete, brick, gypsum board, shingles, and other common components of buildings. C&D waste also includes storm debris, which was generated in large quantities after Hurricane Katrina. MSW is defined as solid waste emanating from households, schools, apartments, and normal collection activities.
7. Chef Menteur, Old Gentilly, Empire Pit, and Kilona are four C&D sites opened in response to Katrina, although data for Empire Pit and Kilona are not available.
8. Section 404 of the Clean Water Act prohibits discharges of dredged or fill material into waters of the United States. A permit is needed from the COE before closure procedures can be completed for the Chef Manteur landfill.
9. The Bring New Orleans Back Commission, the Louisiana Department of Forestry, the Coalition to Preserve Coastal Wetlands, and the Louisiana State University Agriculture Center were a few of the many organizations that formally recommended composting and detailed how it could be integrated into the Hurricane Katrina recovery efforts.
10. When Sheetrock is disposed of in C&D landfills, it leaches hydrogen sulfide, a dangerous neurotoxin.

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