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# Closed Waste Sites as Community Assets: A Guide for Municipalities, Landfill Owners, and Regulators


Office of Research and Development

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# Foreword

The US Environmental Protection Agency (US EPA) is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, US EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory (NRMRL) is the Agency's center for investigation of technological and management approaches for preventing and reducing risks from pollution that threaten human health and the environment. The focus of the Laboratory's research program is on methods and their cost-effectiveness for prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites, sediments and ground water; prevention and control of indoor air pollution; and restoration of ecosystems. NRMRL collaborates with both public and private sector partners to foster technologies that reduce the cost of compliance and to anticipate emerging problems. NRMRL's research provides solutions to environmental problems by: developing and promoting technologies that protect and improve the environment; advancing scientific and engineering information to support regulatory and policy decisions; and providing the technical support and information transfer to ensure implementation of environmental regulations and strategies at the national, state, and community levels.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by US EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

**Cynthia Sonich-Mullin, Director**
**National Risk Management Research Laboratory**

# Executive Summary

Though closed landfill sites are often considered a liability to local governments, many communities have explored innovative practices to repurpose these facilities as community assets. Examples include open-space recreational uses such as parks, wildlife areas, and golf courses, as well as more construction-intensive applications such as parking lots and government or commercial buildings. In addition, more landfills are being developed as hubs for energy and materials recovery. Landfill gas is commonly captured for energy at landfills, and there is a growing interest is solar and wind power application at landfill sites. Some communities cluster recycling and materials recovery operations at their landfill sites, while others go so far as to reclaim closed landfill areas to recover buried assets and achieve more efficient site utilization. Since landfills remain a key component of integrated municipal waste management systems for the foreseeable future, communities should begin to consider landfill sites as potential community assets and plan for future community uses as part of facility conception and development.

This document provides an overview of the common approaches to utilize closed landfills as community assets, as well as the environmental and regulatory challenges faced when implementing these projects. All uses for closed landfills must ensure that the integrity of the final cover system is maintained to ensure protection of human health and the environment. Common challenges to the use of closed landfill sites include landfill gas and waste settlement. Landfill gas, which can be both explosive and toxic at elevated levels, must be controlled in a fashion to minimize buildup in enclosed spaces; site uses must not interfere with existing gas collection operation. As waste decomposes, the landfill settles, and this necessitates routine maintenance of any features placed on the landfill surface; building construction must be undertaken with care and consideration of the long-term topographic changes. A series of case studies document the typical challenges and opportunities encountered by communities attempted to utilize closed landfills as a resource.

Many opportunities exist to better utilize closed landfill sites as community resources, especially when they are discussed early in the design and planning stage of the facility. Several options/factors should be considered to enhance use of a landfill site after closure. When selecting a facility location, the proximity to potential facility users, other industries, and utilities should be considered. The

community should be involved in the decision-making process from the beginning. Site infrastructure should be planned from the beginning to accommodate future site uses. Landfill disposal cells and their associated infrastructure should be configured and located to best conform to future uses and to minimize construction requirements in later years. Technical innovations that result in the most efficient utilization of the facility as an asset should be implemented where possible. Operating the landfill as a bioreactor promotes waste stabilization and reduces long-term issues with landfill gas and settlement. Opportunities to maximize future materials recovery should be considered early, even when the material value does not currently merit recovery.

# Notice

The US Environmental Protection Agency (US EPA) through the Office of Research and Development funded and managed the research described here under contract order number: EP-C-10-060 to Computer Science Corporation, VA. It has been subject to the Agency's review and has been approved for publication as a US EPA document. Use of the methods or data presented in this manual does not constitute endorsement or recommendation for use. Mention of trade names or commercial products does not constitute endorsement or recommendation.

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## List of Abbreviations, Acronyms, and Initialism

| | |
|---|---|
| CHP | Combined Heat and Power |
| CSP | Concentrated Solar Power |
| GCCS | Gas Collection and Control System |
| LCRS | Leachate Collection and Removal System |
| LFG | Landfill Gas |
| LMOP | Landfill Methane Outreach Program |
| MSW | Municipal Solid Waste |
| MW | Megawatt |
| NMOC | Non-Methane Organic Compound |
| NREL | National Renewable Energy Laboratory |
| NSPS | New Source Performance Standards |
| PCC | Post-Closure Care |
| PV | Photovoltaic |
| RCRA | Resource Conservation and Recovery Act |
| US | United States |
| US EPA | United States Environmental Protection Agency |

# 1 Introduction

For several decades, sanitary landfills have provided for the bulk of municipal solid waste (MSW) management capacity in the US. Despite a growing migration toward recycling and energy recovery, landfills will remain an integral part of the nation's solid waste infrastructure for the foreseeable future. Landfill owners and operators are required by federal rules to follow location, design, and operational requirements developed to protect human health and the environment. A key component of these regulations includes requirements for properly closing the landfill after waste acceptance ceases, followed by maintaining and monitoring the site for 30 years of post-closure care (PCC).

Landfill owners and surrounding communities often view closed landfills as both an environmental and economic liability, largely due to the required long-term maintenance and monitoring. However, a variety of opportunities exist to utilize closed landfills for productive purposes so the space can be transformed into an asset for the surrounding community. Throughout the US, communities have converted closed landfills into recreational areas, natural habitats, energy recovery parks, and hubs for sustainable materials management operations. The combined experiences of these efforts provide a strong knowledge base for communities to utilize when planning for future productive utilization of their own operating or recently closed landfills.

The likely long-term role of landfills for MSW management, the lessons learned from repurposing closed disposal facilities as community resources, and the desire to manage our nation's waste in a more sustainable fashion all present communities with a new opportunity: planning future waste disposal facilities from the beginning for use as a community asset. To date, decisions regarding closed landfill utilization have occurred toward the end of the facility's operating life or after closure. By this time, multiple opportunities for beneficial utilization of facility component materials or energy have been lost, or at the least, have become more challenging and expensive to capture. Community leaders, planners, engineers, and operators should consider from project conception the opportunities to leverage existing facility requirements to maximize future asset potential.

A major challenge with utilizing waste disposal sites as community assets is balancing the desire to utilize space and materials for productive use with the need to meet the primary requirement of the facility – protection of human health and the environment. The utilization of an MSW landfill after closure can be a complex undertaking; environmental, health and safety, geotechnical, energy and reclamation issues must be considered when evaluating reuse options for a closed landfill site (summarized in Figure 1-1). The earlier that the desired site uses are identified, the more opportunities will be available to strike the necessary balance between site utilization and meeting protective requirements.

The objective of this report is to provide MSW landfill owners, municipal officials, engineers and local residents with an introduction to the considerations associated with using closed MSW landfill sites as community assets, and planning for future asset utilization at new sites. The focus of this report is on MSW landfills only and does not consider other types of property (e.g., brownfields) that may have some similar technical challenges or potential reuse opportunities. Through the presentation of background information, various resource recovery options, and selected case studies, this report can also serve as a first step for communities in the planning process to help leverage spaces and resources at existing and future landfills as assets.

This report discusses guidance and regulations that have been developed throughout the US related to the use of closed landfill sites. The report additionally discusses planning and conceptualizing landfills as community assets from the outset, and includes a description of innovative approaches for more sustainable landfill management such as bioreactor landfills and landfill reclamation. The report identifies the advantages of involving the community at the earliest stages of development and for designing the landfill to be compatible with end uses appropriate for a site's location, layout, environmental controls, structural requirements, and potential for future recovery of disposed waste.

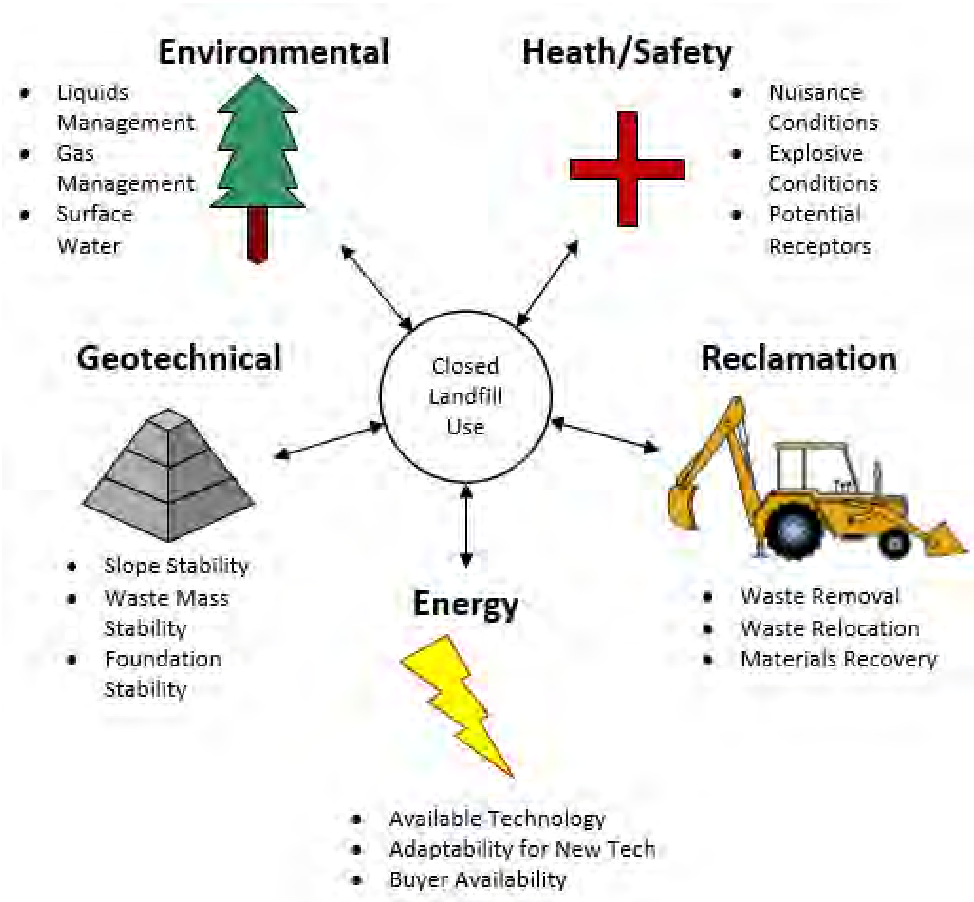


**Figure 1-1. Presentation of Major Categorical Considerations Related to the Use of Closed Landfills**

The report is organized into six chapters. Chapter 2 provides specific details on the common environmental considerations for project developers, including a specific focus on the regulatory constraints that must be addressed. Chapter 3 focus on highlighting opportunities for successful utilization of closed landfills as assets, both for community uses and for energy and materials recovery as well as the challenges that should be expected with such activities. Chapter 4 presents a series of examples of several projects where closed landfills successfully serve as community assets. Finally, in Chapter 5, the opportunities for maximizing site utilization for community benefit from the early planning and design stages of a project are summarized. References are provided in Chapter 6. Included in Appendix A of this report is a detailed listing of identified resources that planners, developers, engineers and regulators can consult to find additional information related to beneficial utilization of waste disposal sites as community resource.

# 2 Regulatory and Environmental Considerations

## *2.1 Overview*

MSW Landfills in the US are regulated by the US Environmental Protection Agency (US EPA) through the Resource Conservation and Recovery Act (RCRA), specifically Subtitle D of RCRA, which was developed to provide provisions for landfills to be operated, monitored, and closed to mitigate human health and environmental impacts. Subtitle D rules dictate that facilities must complete a PCC plan that details how the owner or operator will continue to care for the property after the site closes until the post-closure period ends. PCC must be conducted for a minimum of 30 years, but may be decreased or increased (by the state or jurisdiction with regulatory authority over the site) based on the conditions at the site. At a minimum, the typical MSW landfill PCC plan consists of maintenance and monitoring activities that will be performed at the facility, contact information for the responsible entity during the PCC period, the frequencies that maintenance activities will occur, and the planned uses of the property during the post-closure period.

Since the PCC period of a landfill may go on for many years, it is important when evaluating the future use of a closed landfill, or when planning for the new facilities to accommodate later beneficial uses, that the use does not interfere with the required day-to-day care activities of the landfill or create unsafe conditions. Depending on specific site characteristics, a closed MSW landfill is likely to have the following ongoing activities to control or prevent hazards:

- Maintenance of the integrity and effectiveness of the landfill's final cover
- Maintenance and operation of the leachate collection system
- Maintenance and operation of groundwater monitoring system and
- Maintenance and operation of the gas monitoring system.

Even after the PCC period of a landfill ends, there may still be a need to continue maintenance or care based on potential exposure pathways and risks (this is sometimes referred to as custodial care). Ideally, an MSW landfill would be designed with an intended final use planned, so as the appropriate preparation and development of the site accommodates for potential stressors or failures that may occur based on the intended end use (ITRC 2006). If the originally intended end use of a facility is altered, the newly-proposed end use must be evaluated based on any new potential risks or exposures that may result from the use change.

In this chapter, the regulatory and environmental considerations are discussed in greater detail. First, detailed regulatory requirements related to landfill closure and site reuse are described, both in terms of US federal requirements and selected state requirements. Then, environmental considerations that represent the greatest source of concern with respect to landfill sites (leachate, landfill gas, direct exposure) are discussed.
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## *2.2 Regulations*

The key landfill-related regulations for closed MSW landfills in the US, found in RCRA Subtitle D, lay out minimum specifications that must be implemented upon closure and the subsequent PCC period. State governments have either directly adopted the Federal Subtitle D rules, or they have developed more rigorous requirements that provide additional protection beyond Subtitle D. While the Subtitle D rules not specific about PCC uses, some states do provide outline detailed requirements or guidance for the use of closed landfills. In the rest of this chapter, the US federal rules for closure and LFG are briefly summarized, followed by a description of some of the state-specific landfill regulations that address the use of landfills following closure.

***US Federal Regulations***

Subtitle D requires MSW Landfills to install a final cover system equal to that of the bottom liner system or, if no liner system is present, with a permeability of less than $1x10^{-5}$ cm/sec. The cover system must contain an infiltration and an erosion layer. Figure 2-1 provides a generalized cross section of a typical final landfill cover system. The ultimate goals of the closure criteria are to minimize infiltration and erosion, which will consequently aid in minimizing future environmental impacts (as described later in this chapter).

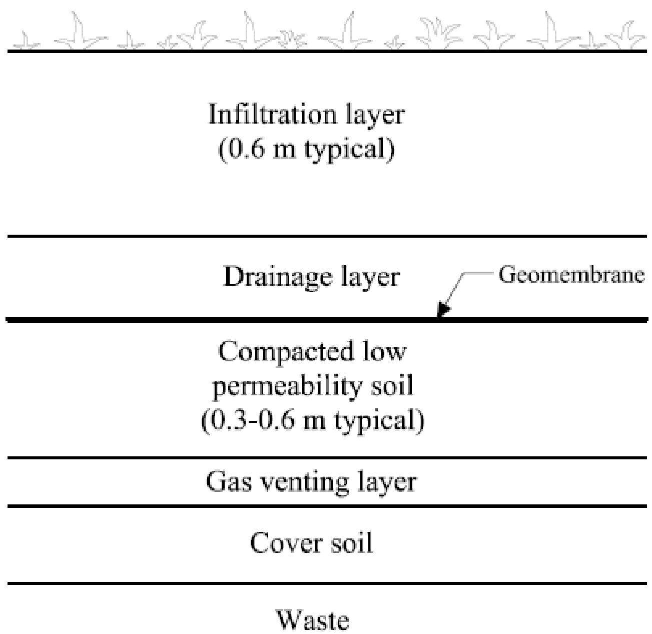


**Figure 2-1. Typical Cross Section of a Landfill Cover System Including Major Components**

During the PCC period, the Subtitle D regulations dictate that the landfill owner complies with several specific requirements. These requirements are outlined in Table 2-1.

**Table 2-1. PCC Requirements for MSW Landfills under RCRA Subtitle D**

| PCC Requirement |
|---|
| Maintain the integrity and effectiveness of any final cover, including making repairs to the cover as necessary to correct the effects of settlement, subsidence, erosion, or other events, and prevent run-on and runoff from eroding or otherwise damaging the final cover |
| Maintain and operate the leachate collection system. |
| Monitor the ground water |
| Maintain and operate the gas monitoring system |

Although design requirements for closure and maintenance requirements for closed landfills are specified in Subtitle D, there are no federal standards for specific use of closed landfills. The generalized language in Subtitle D references requirements that must be met for any post-closure "disturbance" to the landfill site:

> *§258.61(c)(3) "…Post-closure use of the property shall not disturb the integrity of the final cover, liner(s), or any other components of the containment system, or the function of the monitoring systems unless necessary to comply with the requirements in this part 258. The Director of an*

> *approved State may approve any other disturbance if the owner or operator demonstrates that disturbance of the final cover, liner or other component of the containment system, including any removal of waste, will not increase the potential threat to human health or the environment."*

The Subtitle D regulations require that MSW landfills monitor for off-site migration of landfill gas and they do require that off-site odor must be controlled; while these regulations do not specifically require the installation and operation of a GCCS, several US rules under the authority of the Clean Air Act require that landfills of a given size and with a given non-methane organic compound (NMOC) emission rate must collect and control LFG. These regulations include the New Source Performance Standards (NSPS) for MSW landfills, the National Emission Standards for Hazardous Air Pollutants, and the Emission Guidelines for MSW landfills. Under these rules, landfills that exceed the designated thresholds must construct and operate a GCCS; the GCCS and landfill surface monitoring described in the previous subchapter are required under the authority of these regulations. Operation of the GCCS must continue until the landfill is closed and a closure report submitted, the GCCS was in operation for a minimum of 15 years, and the calculated emissions of NMOCs are less than targeted thresholds.

### *State-Specific Conditions for Use of Closed Landfills*

Since state environmental regulatory agencies have the option of developing and adopting rules at least as protective as the federal regulations, several state agencies have taken the opportunity to customize and expand regulations for closed landfill use to fit the unique interests and perspectives of their state. For most state departments of environmental protection (at least 75%), however, a nearly identical recitation of the federal regulations are stipulated. Example of state-specific closed landfill use regulations are presented below. The examples highlighted are not intended to be inclusive of all state-specific regulatory requirements, but rather to provide the reader with a distribution of examples from several states in different areas of the country. Developers and landfill owners should always consult the appropriate regulatory agency with jurisdiction over their site to understand all current applicable regulations for their site. References for the regulations below are provided in Chapter 6 as well as in Appendix A of this report.

The few states that provide additional regulatory instruction incorporate language prohibiting specific types of end uses; describe the application and permit requirements for specific end uses; or provide additional conditions that must be met depending on if construction will occur on or near the waste extents of the landfill. For example, Maine, North Dakota and Wisconsin rules provide a list of prohibited activities for closed landfills (MDEP 2013, NDAC 2009, WAC 2013). The types of activities that are restricted include: construction of buildings on top of or within a specific distance of the waste boundary; use for agricultural purposes (haying may be allowed on a site-specific basis in Maine); grazing; or excavation of the final cover or any waste material.

Texas has a thorough subchapter outlining the use of land over closed MSW landfills. Within the subchapter, the process for obtaining clearance for development of an enclosed structure over a closed MSW landfill unit or a closed MSW landfill in post-closure care is provided. A permit modification or amendment application must be submitted and approved by the regulatory agency. Specific operational requirements outlined in the rule must be followed for construction of a structure. Examples of some of the operational requirements include LFG control (LFG monitoring and monthly reporting of methane sampling), meeting air pollution criteria, and providing proper ventilation. Construction of an enclosed area to be occupied by people under the natural grade of the land or under grade of the final cover is prohibited (TAC 2014).

In Pennsylvania, as part of the initial permitting of an MSW landfill, a two-part application process must be fulfilled and approved. Within the second part of the application, a post-closure land use plan is required describing the proposed use of the facility after closure. The application should include "a discussion of the utility and capacity of the re-vegetated land to support a variety of alternative uses, and the relationship of the use to existing land use policies and plans." The application must explain how the proposed use of the landfill will be achieved and what necessary support activities are needed to fulfill the proposed land use. The application should also identify the considerations that have been assessed to ensure that the post-closure land use is consistent with landowner plans and the applicable State and local land use plans and programs (PaCode 1988).

California requires all non-irrigated land uses of sites implementing closure or closed sites to submit proposed uses to multiple government agencies. One agency specifically reviews and approves projects that involve structures near or on top of the waste. The regulations require that construction of structural improvements on top of landfilled areas during post-closure period must meet several conditions including having automatic methane gas sensors, prohibiting enclosed basement construction, mitigation of the effect of gas accumulation and differential settlement, placement of utilities above the low permeability layer of final cover, acceptable piling installation and periodic monitoring of methane gas inside all building and underground utilities. Additional specific design provisions are listed for any construction that occurs within 1,000 feet of the waste disposal area; these conditions are meant to prevent gas migration into building structures (CIWMB 2014).

Massachusetts regulations require the post-closure use of landfills be reviewed and approved by their state regulatory agency. The usage unless otherwise determined by the agency must not alter the final contours of the landfill, disturb the integrity of the final cover, and all erosion and sedimentation control must be maintained. Additionally, if construction occurs during the post-closure care period of the landfill, buildings must be placed above-grade (basements that penetrate the low permeability of the final cover are prohibited), constructed to prevent gas accumulation within the structure (gas monitoring and warning systems are required; an active gas venting system may be needed), and utility connections should be designed with flexible connections (CMR 2014).

Some states have created guidance documents for owners and operators of landfills to assist in landfill use decision-making. Guidance documents typically provide added insight to the environmental considerations of choosing an appropriate use for an old landfill. In Appendix A, references to guidance documents for the following states have been included: Florida, Indiana, New Jersey, Ohio, Texas, and Massachusetts.

## 2.3 Environmental Drivers

Landfills have the potential to negatively impact water (surface and groundwater) and air resources, thus landfills are required by federal regulations (RCRA) and state regulations to be designed and operated to mitigate these potential negative impacts. During the operational years and throughout the post-closure years of a landfill facility, sites generally have well-established standards to follow to prevent pollution and to control the materials and people that are entering and leaving the facility. When a closed landfill is utilized for another purpose in addition to waste management, the activities at the facility may change, but the ongoing environmental responsibilities of the owner and operator remain. In consideration of these environmental responsibilities, it is important to have a good understanding of the major pathways of environmental risk that must be considered when integrating new activities with a landfill site.

***Leachate***

Leachate forms as a result of the contact of waste with water. When waste is first disposed of in a landfill, some moisture exists within the waste, but most leachate results when rainwater infiltrates into the landfill. At older landfills with no protective liner systems, leachate migrates from the bottom of the landfill into the groundwater; the Federal Subtitle D landfill regulations outlining design (including liner design), operation, monitoring, and financial assurance requirements for MSW landfills were promulgated in 1991. At sites with engineered liners, the leachate is removed via the leachate collection and recovery system (LCRS) and then properly treated. At some sites, leachate "outbreaks" or "seeps" on the side slopes of the landfill occur and must be appropriately addressed to avoid any environmental contamination or human contact.

Leachate can contain a variety of chemicals as highlighted in Table 2-2. Some of these chemicals occur as a result of the waste decomposition reactions in the landfill, while others originate from products or chemicals disposed of in the landfill. When discharged to surface water, leachate poses an ecological risk. When mixed with a drinking water source (such as an aquifer), the water may become contaminated to levels that are no longer safe to drink.

**Table 2-2. Chemical Constituents of Concern in MSW Landfill Leachate, in Order of Most to Least Predominant (adapted from Kjeldsen et al., 2002)**

| Chemical Constituent Category | Specific Chemicals |
|---|---|
| Dissolved organic matter | Quantified as biochemical oxygen demand, chemical oxygen demand, total organic carbon, or volatile fatty acids |
| Inorganic major constituents | Total dissolved solids, calcium, magnesium, potassium, manganese, ammonium, iron, chloride, sulfate, bicarbonate |
| Trace metals | Arsenic, cadmium, chromium, copper, lead, nickel, zinc |
| Trace xenobiotic organic compounds | Hydrocarbons, solvents, pesticides, pharmaceutical compounds |

Landfill operators use several techniques and operational practices to mitigate the possible environmental and human health effects of leachate; many of these are required by regulation. During operation, leachate production is minimized through a process referred to as run-on control and runoff control. By minimizing the amount of water that infiltrates into the landfill, the amount of leachate ultimately generated is reduced. At a closed landfill site, infiltrating moisture is controlled through the placement of an engineered cap designed to shed stormwater off the landfill. Thus it is very important that regardless of the final use of the landfill site, the integrity of the cap is maintained and that the stormwater management system continues to function as designed.

At lined facilities where leachate is captured by the leachate collection and removal system (LCRS), the operator minimizes potential impact on the environment by removing the leachate in a timely fashion so that the head on the liner is minimized. This requires that pumps be operated and maintained, and the LCRS pipes be routinely inspected and if necessary cleaned. An important component to any leachate operation plan is routine monitoring of leachate volumes (and possible depths). For closed landfills, even though the amount of leachate should be reduced because of the presence of the final cover system, the LCRS and its associated infrastructure must continue to be operated and maintained. Sites in PCC uses must accommodate this infrastructure, keep unauthorized personnel or visitors away from sensitive areas, and provide necessary access for authorized personnel to service and monitor the LCRS as needed.

An additional element for related to leachate issues, at both lined and unlined landfills sites, is a groundwater monitoring system. Groundwater monitoring wells are place at the perimeter of the landfill units, both up-gradient of the landfill (to assess the water before it passes under the landfill) and down-gradient (to assess the water after it passes under the landfill). By measuring the concentration of chemicals in the groundwater on a periodic basis (usually twice per year), the operator can evaluate how well the landfill is performing with respect to leachate minimization and containment, and take actions if needed. Groundwater monitoring will continue at closed sites repurposed for other community uses. Similar to the

LCRS infrastructure, the monitoring wells must be protected and the site must be configured and maintained in a manner to allow access. Also very important is providing careful thought to the location of other infrastructure or activities near monitoring wells that might result in future contamination; some activities at a closed landfill site might by necessity require the use of chemical products, that if spilled, could result in groundwater contamination and diminish the efficacy of the monitoring well network.

***LFG***

LFG is generated from the decomposition of organic materials in the waste stream (e.g., food, yard waste, paper products) and is predominantly comprised of an approximate 50/50 mix by volume of methane and carbon dioxide (though trace amounts of other gases will also be present). As LFG is generated within the landfill, pressures develop and cause the gas to migrate from the landfill to the lower pressure atmosphere; gas migrates to the top of the landfill, but may also migrate to the side or bottom of the landfill as well.

LFG can prove problematic for landfill sites for several reasons. First, the methane can be explosive when mixed with oxygen in the right proportion; this is a major concern for buildings (or any structure with an enclosed space) that is constructed on or adjacent to a landfill. Second, the trace components (e.g., hydrogen sulfide) contained with LFG are a source of odors and can also be toxic at elevated concentrations. Table 2-3 summarizes issues with methane and one of the more highly cited problem trace gases, hydrogen sulfide. Finally, landfill gas includes different chemicals that are potent greenhouse gases, most notably methane.

**Table 2-3. Selected LFG Components of Concern Related to Human Health and Site Safety**

| LFG Component | Potential Effect |
|---|---|
| Hydrogen Sulfide | Has a very low odor threshold and nuisance odor (rotten egg); Can cause irritation to the respiratory system, eyes, or skin; Specific gravity greater than air, so gas tends to accumulate in low lying areas or buildings with poor ventilation; At higher concentrations, it can be fatal. |
| Methane | Accumulated concentrations in the presence of oxygen can create explosive conditions; Increases the risk of injury and damage due to explosion and fire. |
| NMOC | Contains compounds that can be toxic or otherwise hazardous to humans, may contain odorous compounds |

In a similar fashion as described for leachate, operators use a variety of techniques and operational practices to minimize potential issues with LFG. Maintaining proper cover soil placement, along with good run-on and runoff practices, can lessen LFG issues, as soil cover can help attenuate gas migration and additional moisture promotes gas production. Upon closure, the final cover system performs these roles, and thus the importance of maintaining the cover and stormwater controls systems as described for leachate control are equally true for LFG control.

Depending on either regulatory requirements or site-specific objectives, the operator may install a gas collection and control system (GCCS). This will normally consist of vertical and/or horizontal wells placed within the waste that are connected to a piping network. The piping is in turn attached to a mechanized extraction system that applies a vacuum to extract the gas to a flare station or some type of energy recovery system (for older sites, gas wells may be vented to the atmosphere). Integrating the GCCS with other site uses can prove a challenge, as the gas collection infrastructure will be dispersed all over the surface of the landfill, including both extraction points (well heads) and buried collection pipes. Operation of the GCCS will continue for many years after closure, and post-closure sites uses must accommodate the GCCS infrastructure. Unauthorized personnel or visitors must be kept away from sensitive areas, while authorized personnel must be provided sufficient access to service and monitor the GCCS as needed. Any new infrastructure constructed on or near the landfill must factor in the location of the GCCS wells and pipes to avoid damage and potential environmental release.

Finally, regulatory requirements normally necessitate that potential LFG migration outside of the landfill be monitored, both at the surface of the landfill and the perimeter. Surface monitoring involves measuring concentrations at the surface of the landfill using a portable meter by walking the landfill in transects. Perimeter monitoring will be conducted akin to groundwater well monitoring, but the gas monitoring probes will be installed in the unsaturated zone above the groundwater table. Monitoring may also be required in the enclosed spaces of any structures on or adjacent to the landfill. Future site uses must accommodate these monitoring requirements.

***Direct Human Exposure***

An additional category of possible exposure, one that would less frequently be encountered at closed MSW landfill sites, is direct exposure to wastes (or soils contaminated as a result of waste, leachate or LFG). When a landfill is closed, in addition to the final soil cover layer, the engineered cap will be constructed on top, and thus wastes should remain buried unless later disturbed. Direct exposure is a more common issue at closed hazardous waste sites or brownfield sites, where chemicals may be spilled or purposefully added to the land over time.

Developers and owners of closed MSW landfill sites should still be cognizant of potential direct exposure pathways as a result of waste disturbance. During site maintenance of infrastructure or construction activities, waste materials may be exhumed or exposed, requiring immediate cover and proper disposal if removed from the site. In addition, routine landfill inspection should consider possible waste exposure as a result of severe waste settlement, burrowing animals, or erosion.

# 3 Opportunities for Community Use of Landfills

## *3.1 Overview*

When considering potential end uses of a closed MSW disposal facility, landfill owners, along with municipal government officials and community planners, have a variety of options that can be explored. Table 3-1 presents an overview of the more common beneficial uses of closed landfill sites. These uses range from those with heavy community interaction (such as a park), to those where the community is benefited through the creation of new energy (placement of solar panels on top of closed landfills). Landfills can serve as an asset to their surrounding community through many avenues. In areas where undeveloped land may be difficult to find, or come at a premium (e.g., densely populated areas with limited green space), the utilization of the open space provides a very tangible benefit to local residents.

**Table 3-1. Opportunities of Post-Closure Landfill Usage**

| Opportunity | Description |
|---|---|
| Recreation | Recreational opportunities range from less intensive and publicly restricted uses, such as a habitat preserve, to more intensive activities such as a sports complex (e.g., ball field, golf course). Recreational uses may be comprised of primarily open space or they may include amenities such as restrooms, concessions stands or other structures and features. |
| Agriculture | Agricultural uses (e.g., crops, haying,) can include planting shallow root crops, which may also substitute for the vegetative layer of the closed landfill. |
| Structural features and buildings | Parking lots, maintenance buildings, retail stores, and other structures have been constructed on old landfills. Most structures built on former waste disposal sites are relatively light in nature, although some projects have involved heavier infrastructure. A landfill site can also serve as a hub for other sustainability-oriented purposes, including environmental educational centers for the community, a location for dropping off recyclables, a center for donating and claiming used or unwanted items, and a drop-off center for household hazardous wastes. |
| Energy generation | Landfill gas (LFG), a product of waste decomposition, can be collected and utilized as an energy source; this is a relatively common practice at larger landfills. Placement of solar panels and wind turbines has also been recognized as a potential good use for landfill sites depending on the geographic location of the landfill and other factors. Landfills that utilize technologies to create energy can generate revenue and reduce greenhouse gas emissions by offsetting fossil fuel use. |
| Landfill reclamation | Reclaiming (or mining) a closed landfill provides an opportunity to remove waste from problematic locations, which may otherwise lead to potential risk to human health and the surrounding environment, so that land use can be maximized and may also result in the recovery of potentially valuable materials (e.g., metals, combustibles, soil). |

When assessing the utilization of a landfill site as a community resource, either an existing facility or one under planning, some problematic issues will pose a challenge to implementing the desired outcomes and necessitate the implementation of remedial or precautionary measures. Table 3-2 presents a summary of the types of challenges typically encountered. It is important to remember landfills are permitted facilities and any changes to the site will require compliance with permit conditions or a modification of the permit; in cases where a change to the permit is needed, the appropriate regulatory permitting authority must be contacted. Regulatory issues are described in greater detail in the previous chapter. The benefits and challenges of utilizing landfill sites as community assets are discussed throughout the report.

**Table 3-2. Listing of Key Challenges of Post-Closure Use of Landfills**

| Challenge | Description |
|---|---|
| Maintaining cover system integrity | Closed landfills are required to have an engineered cover system. Regular maintenance activities are required to monitor the condition of the cover system and repair detected |

| **Challenge** | **Description** |
|---|---|
| | problems. Some beneficial uses might result in cover system damage; inspection and maintenance is required to avoid excess leachate generation, LFG migration, and exposure to waste materials. |
| Leachate management | Leachate is the liquid that results when water contacts waste. Many landfills will have an operational component for leachate management, such as collection and removal from the landfill and subsequent treatment that must continue after the site has been closed regardless of final use. As leachate represents a potential human health risk when exposure occurs, the leachate system needs to be inspected and maintained to avoid any releases. |
| LFG management | A gas collection and control system (or a passive LFG venting system) must be operated, maintained, and monitored to minimize migration to LFG and prevent explosive conditions that can arise when LFG accumulates within buildings or confined spaces; this would be a particular concern for any structure built on top of an area of former waste disposal. LFG use in energy recovery applications (particularly those involving direct use) may necessitate treatment of the gas to remove undesirable constituents. The LFG collection, treatment and utilization system must continue to operate until LFG amounts are sufficiently low, regardless of final use. |
| Groundwater monitoring | Landfills must monitor groundwater until the site's regulatory permit allows this activity to cease. New site uses must still accommodate the presence and access to the groundwater monitoring wells for periodic sampling. Accidental release of chemicals to the ground from other site activities must be prevented. |
| Stormwater management and erosion control | Appropriate stormwater management and erosion control plans must be followed to prevent damage and wear to the cover system and appropriately convey stormwater to the surface water management system. These activities must continue regardless of final site use and must be integrated into any planned site reconfiguration. |
| Surface water protection | Similarly to groundwater contamination, surface water quality can be affected by leachate seeps or from inadequate stormwater and erosion controls. Proper monitoring and maintenance of leachate, stormwater conveyance and the cover system are needed to reduce these impacts. |
| Settlement | Landfill settlement results from waste consolidation and decomposing in the landfill. Settlement can impact the foundation of buildings or other structures, as well as utility connections or other site features, and can damage the cover system and create unsafe conditions at the surface of the landfill. Structures must be designed to accommodate settlement and monitored for the detrimental impacts of settlement (e.g., cracking, depressions). |
| Landfill infrastructure | Managing some of the previously-detailed issues requires the effective performance of landfill containment and control infrastructure. Landfills have a mix of infrastructure built before (if bottom liner system was included), during, and after waste was placed. Any new activities on the site must not negatively impact these vital components for landfill performance. |
| Building/structure stability | Building/construction projects on top of the landfill can be a challenge because the structure must be designed to withstand potential settling issues, address potential LFG migration, and address other factors to ensure proper functioning of the closure system (e.g., avoid interference with the cap system). |

The development of landfill sites into an area that serves as a community asset can take several forms. Some assets serve as direct benefits to the community, such as making available new land area for community activities, wildlife habitat, commercial ventures, or less direct uses such as energy and materials recovery. This chapter focuses on these uses, providing additional details and considerations regarding typical practices, technical considerations, and unique challenges.

## 3.2 Recreational Use

The use of old landfills for community recreational purposes provides an opportunity to enhance leisure amenities for the public and potentially improve property values in the surrounding area. These applications are among the most common beneficial uses of closed landfill sites. Benefits with respect to creation of community recreational space include providing desirable green space to heavily urbanized areas, expanding the availability of nature trails and sports activities to promote community health and wellness, and restoring natural habitats and providing an area to host local wildlife educational programs.

Recreational activities range in complexity from serving as primarily open space with no structural amenities to highly-developed sports complexes with numerous structures. Depending on the characteristics of the landfill, and the attributes desired by the community, a repurposed landfill may incorporate one or many different recreational functions at a site. When determining an appropriate recreational use for an old landfill, in addition to addressing the needs of the community, there are many considerations that should be accounted for. The advantages of and concerns with the major types of recreational use projects are elaborated upon below.

***Nature Sanctuary/Habitat Creation***

The establishment of wildlife habitat areas provides several benefits when compared to the standard closure practice of planting a monoculture of grass on top of the landfill. This practice entails using a variety of vegetation and landscaping features that meet the objectives of the final cover system (minimize infiltration of liquids into the waste and properly controlling stormwater), and in addition provide a more natural setting for wildlife and recreational enjoyment. With the selection of vegetation appropriate to the local climate, including native and/or drought-resistant species, this approach offers potential operational cost savings related to vegetation maintenance. Wildlife habitats created to have a natural appearance should have limited mowing needs in comparison to the grass mowing required with closed landfills only covered in grass. The reduced fertilizer needs of wildlife areas additionally may also result in cost savings (Simmons 1999). Some maintenance controls such as weeding, and inspection and removal of invasive plant species may be necessary to maintain natural habitats.

To successfully launch habitat creation, a pre-development survey should be conducted. These surveys are intended to identify existing species in the area and to characterize the natural prevailing conditions necessary for the habitat. Once the survey has been performed, restoration of the landfill site will normally follow one of three paths (Simmons 1999). In some cases, the natural regeneration of the habitat takes place with little to no human interference. Alternatively, the basic habitat requirements can be first created, including the establishment of vegetation and related landscape features, and then minimal interference takes place during natural development. Lastly, the habitat features can be established and maintained over time to meet desired outcomes.

As with all post-closure landfill uses, care must be taken to maintain the integrity of the cover system functions and to protect both the landfill infrastructure and potential users of the area. Efficiencies and potential cost savings can be realized if closure system components (e.g., GCCS, stormwater drainage structures) are designed in conjunction with the wildlife habitat. If the pre-development survey indicates that wildlife species that inhabit the area might pose a damage risk to the cover system and infrastructure (e.g., burrowing animals damaging geomembrane caps), then provisions such as placement of a stone/cobble above geomembrane should be incorporated into the cover system design to prevent damage to the geomembrane. Similarly, damage to the cap with root penetration should be considered when selection vegetation for closure cap and development of vegetation maintenance plan.

***Parks and Sports Complexes***

Parks or sports fields that consist of primarily open spaces carry some advantages over more complicated recreational approaches because concerns with accumulation of gases within buildings are eliminated. From a surface water management perspective, the needs of open recreational areas are generally not in conflict with closure standards for landfills; rainfall runoff will need to be drained off regardless and conditions of ponded water should be avoided. Open recreational sites may have picnicking sites, benches and trails, but there are typically no structural buildings. Similar to those concerns identified when constructing open spaces for wildlife habitat, care must be taken in more heavily trafficked recreational areas to protect the cover system and the related infrastructure. More maintenance will certainly be required for these types of activities. The installation of signs or similar features to identify areas that should be off-limit or treated with caution may be warranted.

With more user-intensive recreational development projects, a larger number of occupants and activities may be expected, in addition to the presence of one or more structures. Buildings associated with recreational parks may include administration buildings, storage areas, and restrooms. Lighting systems may be required. Whenever possible, such facilities should be located outside the boundaries of disposed waste, but given the potentially large area of many landfill sites, effective recreational use may require some construction above the waste itself. Foundation requirements for these types of buildings, as well as ancillary components such as playgrounds, pavilions, bleachers and concession stands, may require additional soil be placed as a foundation material or that the existing foundation be stabilized. Issues with constructing buildings on top of waste disposal areas are discussed in greater detail in Section 3.4. The control of LFG and the need to avoid explosive conditions will be a major concern discussed.

***Golf Courses***

Golf courses are one of the more popular end-uses for closed landfills, but a relatively large land area is typically required to develop a full 18-hole golf course. Hurdzan Golf (2013) suggested that at least 175 acres are needed to develop a complete golf course. Figure 3-1 provides an aerial view of a golf course constructed on a closed landfill. Golf courses situated in areas of high demand have been suggested as potential net revenue generators (Gross 1994 and Wallace 2000). One of the most significant costs of building a golf course on a closed landfill is the large amount of soil required to provide the grades that are ideal for golfing, where soil material thicknesses may be 30 ft or more. Developers and landfill owners with a goal of utilizing landfill sites as a golf course should consider integrating these future goals into the waste placement plan for the site; if implemented correctly, this practice could significantly reduce the costs associated with additional soil and minimize disturbance of necessary site infrastructure.

**Figure 3-1. Aerial View of Golf Course Constructed on a Closed Landfill (Photo Courtesy of CDM Smith, Inc.)**

As discussed earlier, LFG collection is required for a period of time following closure, so the design and operation of any active LFG collection system must be accounted for in the golf course's design. Since the NSPS rules require operational steps such as monitoring of each gas collection well, access to well components must be provided but balanced with the aesthetic needs of the golf course. In addition to the regulatory need to effectively collect LFG, additional issues can arise if LFG is not properly controlled such as impacts to vegetation.

The anticipated settlement of the landfill following golf course construction must be evaluated as well, since differential settlement can cause ponding or surface grades that could negatively impact the golf playing surface (Figure 3-2 provides a close-up view of a green constructed on a golf course in Florida; maintaining appropriate slopes of the playing surface is important). Unlike some recreational uses, irrigation may be very important for golf courses. Considering the goal of the landfill cover system to minimize water infiltration into the landfill, irrigation systems must be planned, designed and operated to work in concert with the overall objectives of the site. Differential settlement can impact the stability of irrigation lines, and this should be accounted for in design. A large, consistent supply of water must be available at the site, which could be a challenge in some locales; opportunities may exist to use treated water from the landfill for irrigation purposes.

**Figure 3-2. Golf Course Constructed on an Old Closed Landfill (Photo Courtesy of Innovative Waste Consulting Services, LLC)**

***Other Recreational Uses***

Other types of recreational uses have been reported for closed landfills, including ski and sledding slopes, ice skating rinks, and archery ranges, though these types of uses are less common when compared with the more traditional types of recreational projects (i.e., parks and sports fields). In some cases, these reuse options may be limited as a result of regulator or developer concerns with risks from a less commonly practiced reuse project. However, if the project is compatible with community needs and meets regulatory requirements, it is likely that creative recreational solutions to landfill reuse will be considered by regulators and community leaders.

## *3.3 Agricultural Use*

Agricultural uses for closed landfill sites have been proposed, including growing hay, grazing animals, growing crops, and silviculture. The two major concerns with agricultural use are avoidance of any contamination of future food sources from landfill emissions and protecting the integrity of the cap from damage as a result of agriculture activities. Most agricultural uses tend to focus on older landfill sites that do not have intensive infrastructure that would interfere with proposed planting, harvesting or grazing requirements.

Properly closed and maintained landfills should not result in transfer of pollutants from within the landfill to plants or animals on the surface; GCCS maintenance and run-on and runoff control would be key. Avoiding damage or interference with the cover system and related landfill infrastructure would largely depend on the depth of the soil cover and whether it is sufficient to keep plants roots, agricultural machinery, or animals away from critical components of the cap (as well as the waste). Infrastructure should be buried to every extent possible, and where a device is located above ground, it must be appropriate flagged and protected.

The US federal regulations do not specifically address the use of closed landfill sites for agriculture, though the closure uses must be consistent with the necessary function of all closed landfills sites (e.g., cover system maintenance, stormwater control). Several state regulatory agencies do address agricultural uses at closed landfills. Several states outright prohibit agricultural use. Other states may approve the activity based on the proposed use and associated design and facility characteristics (e.g., Indiana and Massachusetts). In the case of Indiana, for example, grazing/pasturing, crop production and silviculture are evaluated based on an extensive list of considerations. These considerations a provided in Table 3-3; those considering agricultural use on landfill sites in other locations would most likely need to provide similar information.

**Table 3-3. Factors to be Considered when Assessing Potential Agricultural Uses of Closed Landfill Sites in Indiana**

| Agricultural Use Consideration |
|---|
| Types of crops or cover to be planted |
| Thickness of additional soils required, including information supporting the adequacy of the depth of soil to support the root zone requirements |
| Required plowing depths |
| Planting application rates |
| Fertilization rates |
| Time required to establish crop production |
| Erosion control measures |
| Equipment required |
| Storage facilities required and location if on site |
| Source and amount of irrigation water (if applicable) |
| Livestock grazing schedules |
| Soil management plan/crop rotation schedule |
| Description of the intended land use changes from its current condition |

## *3.4 Construction and Structural Improvements*

The construction of buildings and other structures on the top of closed landfills was discussed as part of the recreational use development. The types of buildings associated with these uses are often light-duty and often modular or portable. A location for the construction of large, permanent structures is another possible use for closed landfills. Landfills, however, are far from ideal locations for buildings. The two biggest areas of concern relate to the strength of the foundation that building rests upon and the concerns related to LFG migration. This section summarizes issues related to these types of construction projects.

The types of structures constructed on closed landfills have included buildings (including commercial facilities), parking lots, communication towers, and wind turbines (see Chapter 5). The use of landfill sites for the construction of buildings and similar structures is less common than recreational uses because of the greater hurdles (e.g., regulatory, design, economic, long-term safety) that must be overcome to ensure environmental protection and adequate performance of the structures. The US federal regulations do not specifically address building on closed landfills, but several states do. Texas, California, and Massachusetts, for example, have developed regulations which outline requirements specific to the construction of buildings and structures on closed landfills. Additionally, Indiana and Ohio have prepared guidance documents for construction over landfill project submittal requirements (see Appendix A). For example, Table 3-4 provides the considerations that are evaluated in Indiana when considering building construction on closed landfills.

**Table 3-4. Indiana Department of Environmental Management Building/Structure Construction Project Proposal Requirements (IDEM 1998)**

| Component | Details Included |
|---|---|
| Description of Proposed Use | • Design plans<br>• Design calculations<br>• Revisions to existing post-closure plans |
| Demonstration of Maintaining Cover and Liner Integrity | • Need to demonstrate that there will be no increased potential threat to human health and the environment |
| Geotechnical and Structural Engineering Analysis | • Structural fill requirements for foundation<br>• Requirements for in-place waste densification<br>• Additional soil requirements for installation zones of underground utilities<br>• Demonstration that pilings and foundations will not introduce conduits for contamination to enter the natural substrates |
| Construction Requirements for Mitigating Effects of LFG | • Vent system or active GCCS<br>• Automatic methane sensors with audible alarm when concentrations detected |
| Settlement Considerations | • Utility connections with flexible connections and utility collars |

The remainder of this section will focus on three primary issues with building on closed landfills: maintaining the integrity of the cover system, protections from LFG, and building foundation issues, including long-term settlement.

***Maintaining Cover System Integrity***

All proposed uses of closed landfill sites must be compatible with the final cover system and not impede necessary functions such as limiting moisture infiltration, controlling gas, and providing appropriate stormwater drainage. When buildings or similar structures are constructed, the foundation of the building will be placed directly on the landfill surface, thus any potential impact on the cover system components must be considered. Construction permits granted by the regulatory authority will prohibit the penetration or deterioration of underlying barrier layers in the cover system (e.g., geomembranes) and stipulate that added stress to the cover system and drainage layer components be minimized. An additional soil layer or building pad will commonly be required to be placed on top of the final landfill cover; this should be constructed to avoid interference with the site's stormwater drainage system. If future building construction is planned during active landfill operation (waste disposal), the design of the final waste placement topography and the cover system configuration can incorporate features to minimize future construction disturbance associated with building construction.

***Controlling LFG***

As described in Chapter 3, LFG is problematic because it is both explosive and potentially harmful because of the chemicals it contains. Buildings must not only be constructed to avoid interference with the facility's GCCS, but their design and maintenance must include extra precautions to ensure that explosive or toxic conditions do not develop within the enclosed spaces of buildings. A common practice is to require the installation of a geomembrane between the slab of the building and the subgrade. A permeable layer (e.g., 12 inches of clean aggregate) is then placed between the geomembrane and the subgrade to serve as a venting layer. The venting layers will typically contain perforated pipes that vent to a location outside the building, and may be connected to an induced draft exhaust system. Any penetrations through the foundation (e.g., utilities) will require some form of seal be placed to prevent gas intrusion.

Another common requirement for buildings constructed on landfills is some form of continuous or periodic gas monitoring. Methane gas sensors, for example, can be placed within the building or integrated into the foundation venting system under the building and set to provide an alarm when a specific threshold (e.g., 25% of lower explosive limit) is reached. Similar devices could be installed for other problematic gases (e.g., hydrogen sulfide) if these were viewed as a potential concern at the site. Accompanying a continuous gas sensor and alarm should be a safety and evacuation plan for the building. Additional gas monitoring may include collection of periodic samples for later analysis in the laboratory; this monitoring step would allow for a much wider array of chemical constituents to be evaluated.

***Building Foundation and Settlement***

Landfills are not ideal surfaces for building construction; compacted wastes do not have the same strength as provided by soil. Engineering and construction techniques are available, however, that allow buildings to be constructed on lower quality foundation materials. When designing a building foundation for landfill surface, two issues that must be considered are the bearing capacity of the landfill surface and the potential for long term settlement. The bearing capacity describes a foundation's ability to support the loads applied to the ground surface by the placement of a structure. When designing a building foundation, a geotechnical engineer will estimate the foundation's bearing capacity based on the properties of the underlying soil and design a suitable foundation. For construction projects on the top of closed landfills, depending on the thickness of type of soil overlying the waste, additional soil fill may be required.

While bearing capacity addresses a near-term evaluation of whether the soil (landfill) surface can support the weight of a building, a longer-term and more problematic issue relates to landfill settlement. The surface of a landfill settles as a result of changes within the waste over time that produce a decrease in waste volume (and waste height). Settlement in an MSW landfill can be attributed to several processes: physical and mechanical (e.g., reorientation of particles, movement of fine materials into larger voids, and collapse of void space); chemical processes (e.g., oxidation); dissolution processes (dissolving soluble substances by percolating liquids and subsequent formation of leachate); and biological decomposition (organics in the waste degrade over time controlled by temperature, humidity, and percentage of organics and nutrients in the waste) (Sharma and Anirban 2007). Settlement typically occurs within two phases; the primary phase occurs as the initial settlement of the landfill due to physical and mechanical processes and typically occurs within the first few months after the waste is placed. Secondary settlement occurs over a much longer period of the time and results from physicochemical and biochemical decay and occurs under constant load after the completion of primary settlement.

Different methods have been developed to predict MSW landfill settlement over time, which is an important consideration when determining the end use of the landfill property. Typically, an older landfill will have fewer issues with settlement than a newer landfill that may still be undergoing self-weight settlement. When developing over a landfill, predicted settlement maps and a monitoring plan should be prepared to facilitate the design and create an effective operation and maintenance plan. Long-term settlement from self-weight and external loads can result in differential settlement that can result in tilting of building support system, ponding of water in parking lots, cracking of slabs supported on the ground, breakage in utility lines and down-drag forces on piles that support heavy building loads. Figure 3-3 shows a parking lot constructed on a closed landfill and the resulting settlement that has caused water ponding.

**Figure 3-3. Parking Lot Constructed on a Closed Landfill (Photo Courtesy of Innovative Waste Consulting Services, LLC)**

For constructed surfaces such as parking lots, settlement can be accommodated by including larger slopes. For structures, building foundations should be designed to accommodate settlement. This can be accomplished with the use of mat foundations (which better distribute the load), flexible connections and utility collars. Soil strengthening or soil stabilization is often used to prepare soft soils for building construction, but this may be limited for landfills because of the need to maintain integrity of the cap. One step that the operator can undertake during operation of the landfill is the purposeful enhancement of waste stabilization and landfill settlement through operation of the landfill as a bioreactor; this technique is described in greater detail in Chapter 5.

## 3.5 Energy and Resource Recovery Oriented Use

Another use of a closed landfill site as a community asset takes the form of using the site as an energy generation project. Energy projects at landfills could possibly be coupled with other uses such as recreation (appropriate restrictions and safety precautions would be needed), but in cases where the landfill is only utilized as an energy project, the risk to potential receptors is typically less since the people accessing the site are approved personnel.

Many landfills around the US now utilize LFG as an energy source; the same methane that represents an explosive gas risk when captured can be converted to electricity (or used in other fashions). In addition to LFG use, the deployment of solar panels or wind turbines at landfills represents another potential renewable energy opportunity. The production of energy at a landfill could provide a series of benefits to the site and the community, including offset of all or part of the electricity needs for the site, offsetting of non-renewable energy resources, and providing further incentive for increased LFG collection, which can have ancillary environmental benefits such as greenhouse gas emission reductions and reduction of potential nuisance emissions.

This section details information regarding the three aforementioned renewable energy project types (LFG to energy, solar, and wind) and key considerations related to implementing one or more of these technologies at a closed landfill. It also includes a discussion of possible resource recovery from reclamation (mining) of the landfilled waste. Reclamation has the potential to enhance a landfill's value as a community asset through the more efficient use of site space, the recovery of resources, and possibly the recovery of a fuel for energy production.

***LFG Recovery***

As described earlier, the primary components of LFG are methane and carbon dioxide. When LFG is extracted through a facility's GCCS, the gas is ultimately either burned in a flare or utilized as an energy source. In its raw form, LFG can be used as a fuel to produce electricity with minimal processing requirements. It can also be cleaned up to increase the energy content for other applications. A summary of the major LFG energy conversion technologies is provided in Table 3-5.

**Table 3-5. Summary of LFG Beneficial Use Technologies**

| Technology | Description |
|---|---|
| Cogeneration (Combined heat and power, CHP) | Generate thermal energy and electricity from steam or heated water. Can be installed to recapture heat losses from turbines and engines thus increasing the processes overall efficiency to up to 80% (US EPA 2008). |
| Combined Cycle Engine | This system utilizes both gas and steam turbines. The gas turbine provides the heat needed to generate steam that is then fed to the steam turbine. Combined cycles are utilized for scales larger than most internal combustion projects. |
| Gas Turbine | Can operate at lower gas concentrations; gas turbines typically require larger amounts of gas for economic feasibility. More resistant to damage than other systems. Electrical efficiencies range from 40% to 80% (Dudek et al. 2010). |
| Internal Combustion Engine | A common type of electricity generation technology, efficiencies typically range from 25 to 35%. |
| Microturbine | Smaller scale combustion turbines. These turbines are employed in areas with smaller gas flow rates. Pretreatment of LFG to remove moisture is necessary in addition to the usage of activated carbon to remove as much impurities as possible due to damage these impurities cause to the combustion chamber. Microturbines can operate at low gas concentrations. Efficiency for this system ranges from 20% to 30% (Dudek et al. 2010). |
| Boiler/Steam Turbine | LFG is directly used by combusting it to a large boiler to generate steam that is to be fed to a steam turbine. This system is not commonly used for LFG electricity applications (Dudek et al. 2010). |
| Stirling Engine | An external combustion engine which mixes air and fuel within the cylinder of the unit to facilitate combustion. Pretreatment of LFG is not needed because of the engine's high tolerance for siloxanes and other such impurities. An average electrical efficiency obtained is 30% (Dudek et al. 2010). |
| Fuel Cell Technology | Fuel cell technology for LFG involves the fuel (i.e., LFG) entering into a compartment where it reacts to produce electrons, air enters another compartment where it reacts to consume atmospheric oxygen and the electrons produced by the fuel (Messenger 2013). The technology's potential for LFG to energy projects is contingent on gas quality, high levels of methane and low concentrations of diluents or trace contaminants are considered ideal for fuel cell conversion (Spiegel and Preston 2003; Messenger 2013). |

The amount of energy that can be harvested from LFG depends on numerous site factors including landfill size, waste age, GCCS coverage and efficiency, and the type of technology used to convert the collected LFG to energy. The US EPA's Landfill Methane Outreach Program (LMOP) estimates that over 600 operational LFG to energy projects are currently active in the US producing a total of approximately 2,000 MW of power. LMOP also estimates another 450 candidate landfills in the US with potential for implementation of a LFG to energy infrastructure. The economic viability of a LFG-to-energy project most often depends on the amount of LFG produced, local availability of direct use applications, the price at which electricity will be purchased for, and the availability of other incentives such as tax benefits or renewable energy credits.

LFG capture for energy is well developed in the US and a common stage in the operating life of large landfill facilities; it may start during the operational years of the landfill and will continue long after the landfill is closed. Landfill owners and operators can take several steps to enhance the asset value of a LFG-to-energy system through early planning. As will be discussed in greater detail in Chapter 5, gas can be captured early in a landfill's operating if the proper steps are implemented, and technologies such as bioreactor landfill operation can enhance the rate at which gas is collected during the peak operational years of the facility (and leave less gas as an issue to deal with after closure). Early planning of the GCCS with respect to other future site beneficial uses (e.g., planning for other power generation, integrated GCCS infrastructure with other site uses) would allow for greater overall site utilization as a community asset.

***Solar***

The potential for landfills as a host for solar energy projects has gained interest in recent years as the cost of solar systems has decreased. Landfills inherently have large open spaces that may not have other uses (often referred to as marginal lands), and they often are equipped with electricity distribution infrastructure as a result of LFG projects (Millbrandt et al. 2013). Solar energy panels utilize radiant heat and light from the sun and convert the energy into usable electricity. The two major types of solar power technologies are photovoltaics (PV) and concentrated solar power (CSP). PV uses semiconductors to create an electrical charge through the PV effect while CSP uses lenses and mirrors to focus and concentrate sunlight. PV systems are the most commonly utilized solar technology (US EPA 2012). The placement of solar panels can be accomplished through fixed systems (e.g., mounted in a fixed configuration) or the panels can be applied to the surface of a landfill such as on geomembrane panels. Figure 3-4 shows a solar energy system at a facility in the Southeast US consisting of flexible panels mounted on the landfill side slope. Messics (2009a) suggested that placement of solar panels on flat areas or south-facing direction was desirable. Tansel et al. (2013) reported that construction difficulties and potentially increased costs are associated with constructing solar panels on side slopes and can create complexities with stormwater management systems.

Several factors must be considered when evaluating a landfill site as a candidate for solar energy production. First and foremost is the amount of available solar energy available in the region of interest. The National Renewable Energy Laboratory (NREL) has developed Solar Radiation Resource Maps which display the average annual solar radiation on a daily basis across the US. Figure 3-5 presents the NREL solar radiation map corresponding to data from 1998 through 2009. Additional factors include the policy and economic incentives, relationship with the local electrical utility, site logistics for power transmission, and site security. Table 3-6 summarizes many of the considerations that go into determining the feasibility of a solar project at a landfill site (as described by Messics (2009)).

**Figure 3-4. Flexible Panel Solar System Installed on an MSW Landfill (Photo Courtesy of Carlisle Energy Services Inc, http://bit.ly/XCI6q2)**

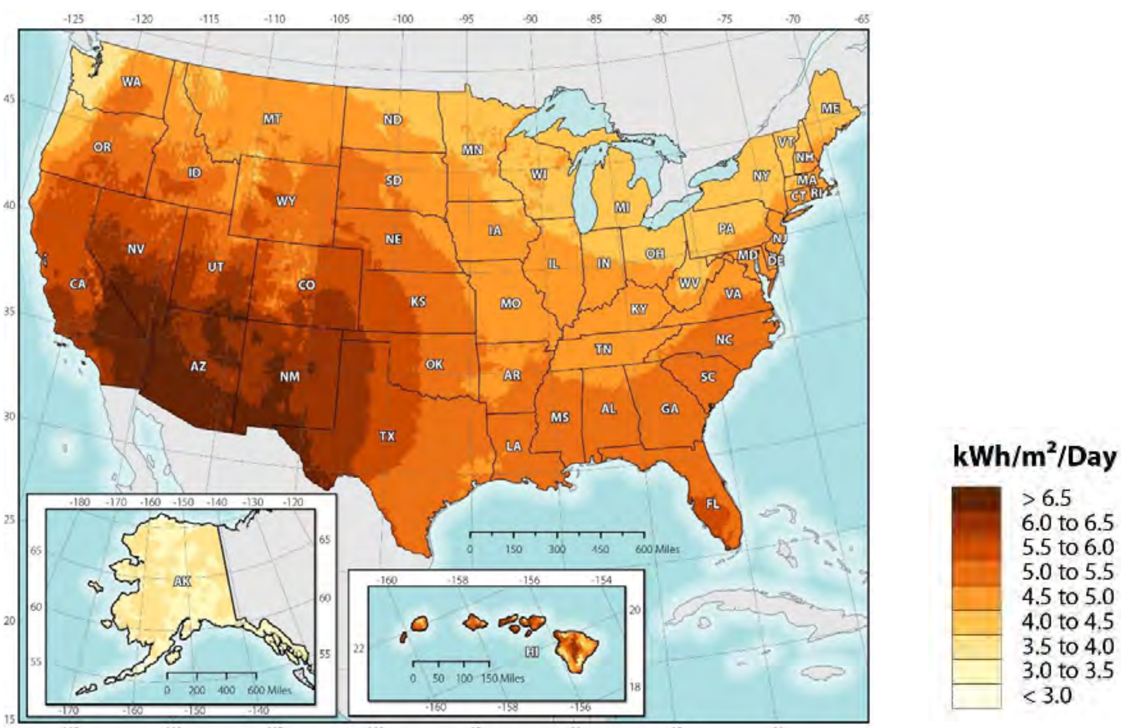


**Figure 3-5. PV Solar Resource Map - Annual Average Based on Data from 1998 to 2009 [Photo Courtesy of NREL (2012)]**

The construction of a solar system on top of a closed landfill would need to be constructed in a manner that did not interfere with the final cover system and other closure components. For ground mounted solar panels, the excavation into the cover system and placement of structural supports would need to avoid any damage to the cap and thus may require a different design than used for typical soils. The placement of the panels would need to avoid interference with the GCCS or the stormwater management system, and allow landfill personnel sufficient access for monitoring and maintenance.

**Table 3-6. Summary of Factors Influential to Solar Project Development at Closed Landfills**

| Influencing Factor | Desirable Features |
|---|---|
| Energy Policy | Locations that provide energy policy incentives for solar power. Examples include standard requiring 2% or higher of region's electricity mix to be from solar; multiplier credits for solar energy. |
| Financial incentives | Grants, tax credits or incentives, customers willing to pay more for solar power (e.g., colleges, corporations, government) |
| Landfill Location | Location in an areas with a high solar potential (from solar resource maps) and unobstructed sunlight |
| Site Security | Completely fenced; panels out of danger zone (e.g., out of rock-throwing reach) |
| Project economics | Credit-worthy counterparties; labor cost control flexibility; high visibility (for marketing purposes) |
| Power logistics | An existing connection to the power grid through an existing LFG to energy system, as well as an access road and a landfill cap of at least 2 ft thick (for trenching of electric lines); a cooperative electric company to help facilitate reasonable costs and schedules. |
| Topography | Flat topography is generally preferred for mounting. South facing slopes can be used if necessary; however mounting is more difficult, and requires increased stormwater and erosion control efforts. |

### *Wind*

Similar to solar energy projects, wind power projects have garnered growing interest in recent years as a potential option for closed landfill sites (wind power projects also need large areas of land). Wind turbines convert wind energy into a usable form and can either be grouped together in a wind farm or used individually. The presence of sufficient wind resources is a prerequisite for a feasible project. NREL has developed wind resource maps that can be used as a preliminary guide to determine whether a landfill location should be preliminarily considered for a wind-power project (Figure 3-6). Site specific studies can also be conducted at the proposed location to provide a greater degree of certainty with respect to design decisions and financial feasibility. As an example, a 12-month wind assessment study was conducted as part of evaluating the feasibility of wind turbines at the Frey Farm Landfill, Pennsylvania, which allowed for the acquisition of actual wind speed data and other performance metrics (Figure 3-7 presents an image of the two wind turbines at this site).

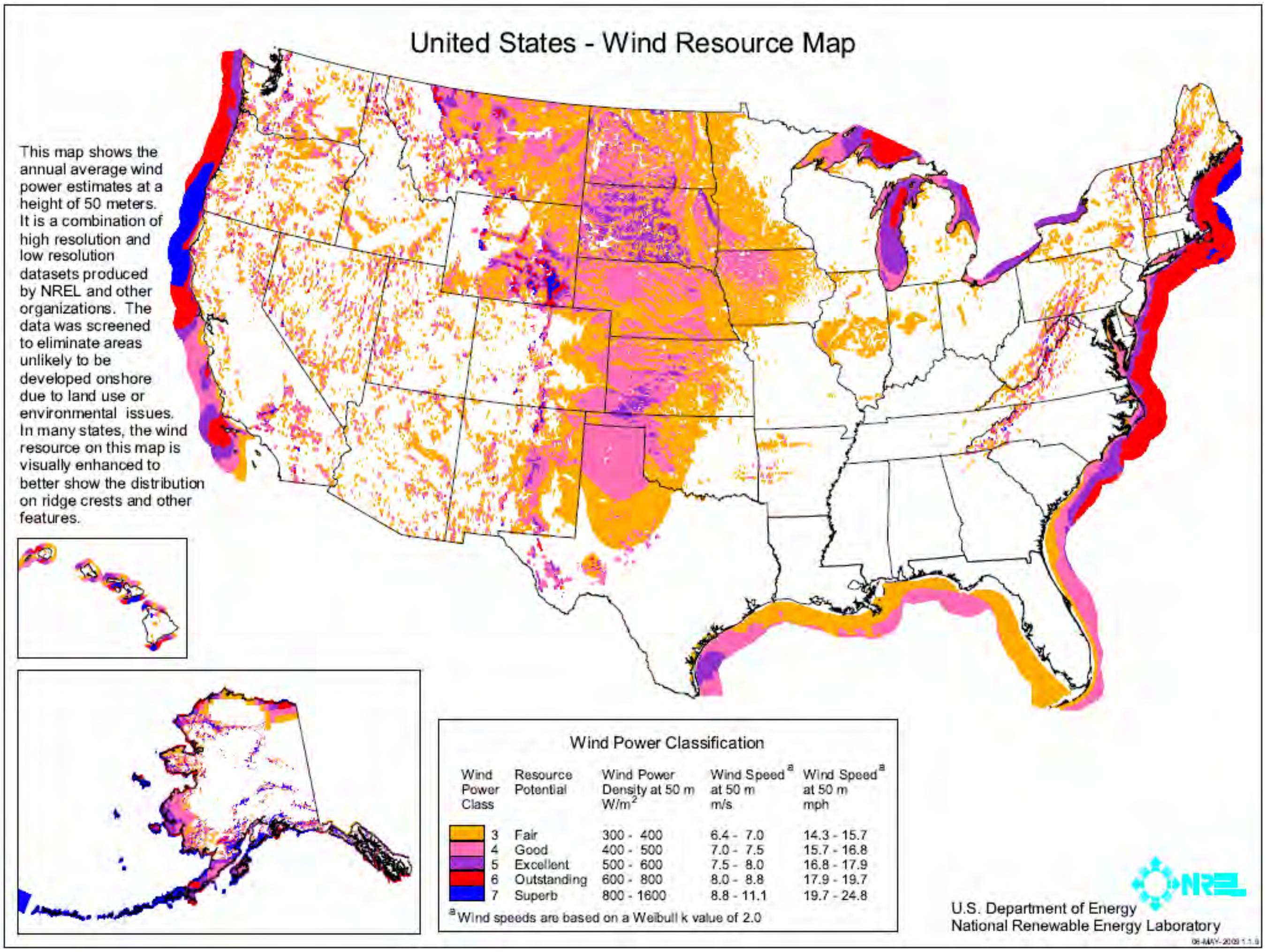


**Figure 3-6. Wind Power Resource Map in the US [Photo Courtesy of NREL (2009)**

**Figure 3-7. Turkey Point Wind Project at LCSWMA's Frey Farm Landfill in Conestoga, PA (Photo Courtesy of www.lcswma.org)**

The siting of wind turbines at landfills is less well-documented than solar project siting. The US EPA (2014) reported 336.0 MW of installed power capacity for wind projects on marginal lands (more than double the solar capacity), but most of the installed capacity was on brownfields or similar contaminated sites (not municipal landfills). A few wind turbines have, however, been located on closed landfills, including in Massachusetts and Pennsylvania.

One geotechnical consideration when constructing wind turbines on closed landfills is the foundational stability of the turbine base and the rotational motion associated with the turbine blade. Geotechnical properties of interest include soil bearing capacity, electrical resistivity of the soil, subgrade characteristics (Yun et al. 2011, Miceli 2012). Installation of the necessary foundation for a wind turbine would require site specific borings and sample collection, and a detailed geotechnical engineering design. The foundation may require some placement with in the landfilled waste, and thus the cover system and geomembrane cap (if present) would need to be modified to make sure that cover system integrity was maintained. Grounding of wind systems and generators is also very important; 35 annual turbine related fires were reported for California alone, attributable to short circuiting and lightning. Safety features, such as mitigation relays, can be installed which allow the immediate shut off of turbines and reduce the chance of system damage and risk to personnel and environment (Panetta, 2010).

***Landfill Reclamation***

Landfill reclamation is a term used to describe the excavation and removal of waste from a landfill; it is also commonly referred to as landfill mining. In many cases, the waste is processed via screening and ferrous metals are often removed using magnets. Landfill reclaiming is included as another option for utilizing closed landfill sites as community assets because of the opportunity it provides to remove waste from problematic locations (so that desired land use can be maximized) and to recover potentially valuable materials (e.g., metals, combustibles, soil). Figure 3-8 shows a landfill reclamation project at a municipal landfill in Florida. More details on landfill mining activities at this site can be found elsewhere (Jain et al. 2013).

At closed landfill sites where waste has been disposed of over large areas often at relatively shallow depths, landfill reclamation provides an opportunity to recover useful land for other applications and to avoid the problems associated with construction on top of waste as described before. In this process, some of the mined materials can be recycled (primarily ferrous metals) and the screened soil can be used to replace virgin soil in other landfill operations or potentially elsewhere as part of final site construction (e.g., grading for golf courses). Once the soil (which includes biodegraded organic matter) is screened out, much of the remaining material consists of combustible material (e.g., wood, plastic), and there is growing interest in using this material as engineered fuel in industrial units such as cement kilns. Finally, when employing technologies to operate the waste as a bioreactor, landfill reclamation offers an opportunity to recover treated waste. The potential concerns with landfill reclamation project include odor, dust, and litter control, unearthing of hazardous waste and other waste materials that are not permitted (by the prevailing regulations) for disposal in landfills, and leachate and stormwater run-off control.

**Figure 3-8. View of Screening Waste Materials at a Landfill Reclamation Project in Florida (Photo Courtesy of Innovative Waste Consulting Services, LLC)**

# 4 Examples of Successful Asset Utilization

Building upon the information presented in the previous chapter, this section provides five case studies of closed landfills that have been converted to a community asset. Case study sites were selected based on a review of available information, literature, and further data regarding site details, landfill reuse system design, and information on accomplishments and challenges associated with the site development and subsequent use. These case studies highlight many of the challenges and opportunities that have been discussed this far, and are intended to provide the reader with a good sense of the steps that different entities have undertaken to transform a closed MSW landfill into a community resource. For the most part, planning for final use of these sites did not occur until after the landfills were either closed or near closure. In the following chapter, considerations for planning final site use from the very beginning of site conception are discussed.

## 4.1 Cesar Chavez Park

In 1991 the Cesar Chavez Park (formerly North Waterfront Park) in Berkeley, California was established on top of the city's former landfill. The facility is located on a peninsular tract of land that extends north along the coastline between the San Francisco Bay and the North Basin. The landfill was originally formed by filling in and diking a portion of the Bay with rip rap, clay and mud to form the landfill. The landfill accepted approximately 1.75 million tons of mostly household waste up until the early 1980s. The landfill was closed in phases between 1981 and 1990 and was capped according to California regulations at the time. Since the closure of the landfill in 1991, the park has been open for public use. The total footprint of the park is 90 acres which includes picnicking areas, hiking trails, shoreline and wetland areas, a seventeen acre off-leash dog area, and wildlife sanctuary. The park hosts various events throughout the year including an annual kite festival. Figures 4-1 and 4-2 show views from Cesar Chavez Park.

When the landfill was closed, it was capped with one foot of clay and a minimum of four feet of topsoil. To construct the park, approximately 500,000 tons of topsoil were brought to the site to create a series of hills and a surface water management system. The landfill also includes an active LFG collection system including approximately 65 individual collection wells that route gas to a continuously-operated flare station. The quantity of LFG collected decreased over time necessitating routine adjustments to the operational conditions of the flare station.

Although no structural facilities were constructed on the landfill itself, the potential for LFG to migrate through the soil into the foundation of a nearby hotel located 300 feet south of the site was a concern. To evaluate LFG concentrations (particularly methane), a series of approximately 10 probes were installed around the hotel perimeter to continuously monitor methane levels. The site's operational procedures also include routine monitoring of leachate seepage on the landfill surface and surrounding areas.

The location of the site on the San Francisco Bay additionally subjects the landfill to natural wear due to tidal action. This scenario, coupled with waste settling, has over time eroded and sloughed off some of the originally-placed armor rock therefore necessitating maintenance. Another maintenance issue has been burrowing wildlife such as ground squirrels and pocket gophers that cause damage to the cover system and stormwater drainage structures. Public feeding of the rodents has increased their population and in turn increased damage due to their burrowing. There has been great public opposition to the proposed removal and trapping of the animals and for the effect it may have on Western Burrowing Owls (a species of concern within the state of California) which utilize ground squirrels as source of food and for their abandoned burrows. Options are currently being explored to address the challenges of balancing the site's unique ecosystem with the environmental protection responsibilities of the landfill.

**Figure 4-1. Overlooking a scenic view to the north of Cesar Chavez Park (Photo Courtesy of Daniel Ramirez, Flickr, http://bit.ly/1mGwTQi)**

**Figure 4-2. View of the trails at Cesar Chavez Park (Photo Courtesy of Daniel Ramirez, Flickr, http://bit.ly/1kSSQVq)**

## 4.2 Cross State Site

The Cross State Site is a 74-acre former landfill site located in Palm Beach County, Florida. Solid waste was disposed of at the landfill from 1938 until 1976. During this time, 2.5 million cubic yards of garbage, including household waste, wood and construction and demolition debris, was accepted at the facility. The site also housed an adjacent ten-acre junk yard and twelve-acre asphalt batching operation. The total waste footprint of the site is 54 acres. Based on its centralized location in the county, the potential land purchase savings, and benefits to the surrounding community, the two owners of the properties, the Solid Waste Authority of Palm Beach County and Palm Beach County, redeveloped the site into four parcels: a concrete and asphalt recycling facility, a vegetative waste recycling facility, a fire rescue training and administration complex, and a Sheriff's driver training pad.

The Sheriff's driver training pad areas and the eastern portion of the fire rescue training facilities, including a four story burn building, a vehicle extraction area, various other light structures, roads and pavements, are located within the footprint of the landfill. During construction, efforts were made to avoid disturbing the cover of the landfill and to supplement as needed with fill to provide an effective sub-base for the roads and driving courses. For minor structures, mat foundations were installed to provide a system where the mat could move with the consolidation of the landfill and also provide a surface to distribute the loads over a larger area while creating an impervious surface for the collection of fire water to avoid point infiltration issues.

To avoid settlement issues with the fire rescue training building (a more substantial structure), waste material was excavated and then backfilled with acceptable material to provide a more stable base for the structure. Flexible paving systems were an important consideration for the driving pad areas that would likely be affected by settlement over time. The site used a minimum of twelve inches of recycled asphalt material available from the adjacent recycling operations with a stabilized sub-base fill as an inexpensive and easy method of maintaining the driving courses. Repairs are made by filling depressions with recycled asphalt material.

The site was sufficiently old at the time of the redevelopment project and therefore significant LFG generation was not expected. A methane gas screening survey was conducted to detect combustible gas just below the surface of the landfill in areas with proposed structures. There were detectable levels of methane, however for open air training purposes, it was determined that the low levels of methane would not interfere with use of the site. Appropriate methane exclusion methods such as under-drain piping in gravel beds to intercept and release gas and sealing off conduits as utilities enter buildings or exterior transformers and panels were still necessary precautions (and retrofits) for buried utilities and enclosed structures.

Additional design aspects of the project that have contributed to the success of the site include an integrated stormwater management design that improved flooding protection; an open stormwater conveyance system that avoided using buried pipes that could be damage due to settling; and using high density polyethylene sanitary force mains servicing the landfill structures to provide maximum piping flexibility.

Since the Cross State Landfill ceased operations prior to landfill design requirements and was not required to undergo closure permitting, the project was given more regulatory flexibility than would be expected with current design regulations; however the project still necessitated the cooperation from multiple agencies and stakeholders to successfully complete the project.

## 4.3 Millennium Park

The Gardner Street Landfill served as an MSW disposal facility in West Roxbury, a neighborhood of Boston, Massachusetts. The 85-acre landfill is located on a 98-acre parcel of land. In 1997, a post-closure plan was developed by citizen's advisory committee working with the public works department; the goal was to develop a plan for revitalizing the landfill to provide public access. In order to properly close the landfill for the proposed post-closure use, the landfill needed to be re-graded, shaped, and capped. Construction soils largely consisted of soils excavated from a major construction project nearby. An active gas collection system, as well as a clay cutoff trench, was also installed, and the adjacent brook was remediated. Site investigations including waste delineation, electromagnetic terrain conductivity survey, and site sampling; these were necessary in order to address potential risks in order to ensure public health and safety through the use of the landfill as a park for the city of Boston.

A traditional closure cap as described by Massachusetts regulations was deemed acceptable for closure, along with the construction of an active gas collection system for long-term closure. The landfill cap consisted of (in order of bottom to top) a gas venting layer, a low permeability barrier layer, a drainage layer, and a vegetative support and protection layer. The active GCCS for the landfill was constructed of 58 extraction wells and included more than 8 km of header and lateral piping. Gas was routed to an enclosed flare. The state approved the installation of seven groundwater monitoring wells and required semi-annual monitoring for a period of 30 years post-closure.

Following the landfill closure, the facility reopened as Millennium Park in 2000. Millennium Park consists of approximately 100 acres of trails, fields, and nature areas. It also includes six miles of walking paths that circle the former landfill, three paved walking loops, and in between the walking paths, 26 acres of playing fields and a playground. Figure 4-3 show the walking trails and picnicking areas at Millennium Park. A small amphitheater was also constructed. One of the highlights of the park is a canoe launch on the Charles River that provides accessible to the public to enter the river in their canoes and kayaks (shown in Figure 4-4).

**Figure 4-3. Millennium Park Paved Trails and Picnic Tables (Photo Courtesy of Dan Brody, www.newtonconservators.org)**

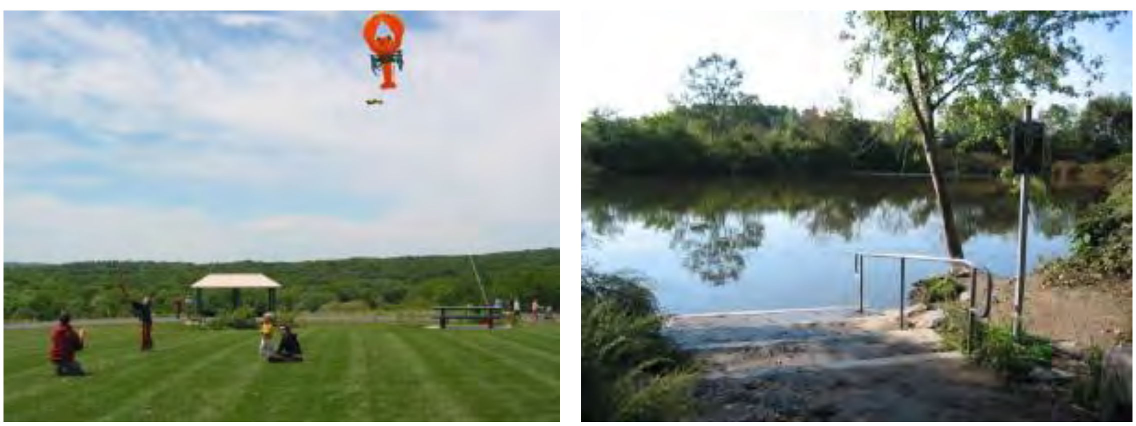

**Figure 4-4. Millennium Park Kite Festival and Canoe Launch (Photo Courtesy of Dan Brody, www.newtonconservators.org)**

## 4.4 Colma Landfill

The Junipero Serra (Colma) Landfill is a solid waste landfill located in San Mateo County, California. In 1983, the landfill was closed after reaching waste depths of 130 feet in some areas ($E^2$ 2007). Ten years following the closing of the Colma Landfill, the site was slated to be developed as a Home Depot (Figure 4-5 shows a view of the big-box store that was built on the landfill). Due to its proximity to San Francisco, the landfill property was an excellent location for commercial business. In the Bay Area of California, deep foundations are necessary due to the soft Bay mud. A total of 710 steel H piles were driven into the landfill, spanning up to 181 feet in length traversing the depth of the landfill (Fittinghoff 2014). The piles were designed to transfer the structural loads to the bearing soils located below the landfill. The Colma Landfill was able to utilize pilings to stabilize and support the structure because it was an older, unlined landfill, and thus there was no liner to damage. The pilings were driven into the bedrock underneath the landfill. Estimates of expected settlement were conducted based on empirical observations and numerical models.

To accommodate for settling, gas wells and collection lines were constructed with flexible piping. A total of nine extraction wells, eight extraction trenches, and 1,850 ft of gas collection header piping were placed below the foundation of the building (McLaughlin and Miller). A geomembrane was placed beneath the building, as was a gas venting system to prevent LFG migration into the structure. When the barrier layer was interrupted for utilities to enter the building, the penetrations were sealed using butyl tape, polyurethane sealant, or special boots ($E^2$ 2007). As an added measure, methane monitors were placed within the building and programmed to set off an alarm when methane concentrations reach 1%. Ramps on the parking structure and connecting features were constructed with hinges, designed to handle some settlement before repairs are necessary. Over time, facility components have required maintenance, including bringing more soil into the site to fill in low areas, repairing the ramps, and keeping the gas system working.

**Figure 4-5. View of a Big-Box Store Built on the Colma Landfill (Photo Courtesy of CalRecycle, http://bit.ly/1yheajY)**

## 4.5 Los Alamos County Landfill

The Los Alamos County Landfill began accepting waste in 1974; it accepted local MSW and waste from the Los Alamos National Laboratory until 2008 (Wheeler 2007). Closure was initiated in 2008, although minimal waste filling occurred from 2008 to 2012 (to bring the site to final closure elevation) (Nagawiecki et al., 2013). The site is unlined, outfitted with substantial final cover material. Upon closure, the County placed solar panels on the landfill and transfer station for waste and recyclables was constructed adjacent to the closed landfill (Nagawiecki et al., 2013).

Los Alamos County Landfill is located in an area with high energy generation potential according to US NREL (2012) solar resource maps. Final cover was installed incorporating consideration of the PV system (Shaw 2011). Panels were mounted on a unique modular tray system and electrical wiring connecting to each panel was connected above the landfill surface, making it possible to complete the project on the newly closed landfill, conforming to contours on the site surface and allowing for disconnection and landfill maintenance (Rafael De LaTorre, personal communication, 2014; see Figure 4-6). Table 4-1 provides an overview of how many of the challenges to site permitting, construction and operation were addressed.

**Figure 4-6. Los Alamos Landfill Site (Photo Courtesy of Los Alamos Department of Public Utilities**

**Table 4-1. Aspects of the Los Alamos Landfill Site and Associated Environmental Controls**

| Project Aspect | Description of Closure Plans and Environmental Controls |
|---|---|
| Solar panel system (14.7 acres) | The PV system plateau was installed with a unique racking system to avoid puncturing the landfill cap. The following layers provided protection when mounting the panels: 12-inch intermediate soil cover, geosynthetic clay liner, 18-inch protective soil layer and 6-inch gravel. |
| Recycling park (8.5 acres) | The facility processes concrete, tires, metal, manure, and compost; a protective cover system (similar to what was installed for the solar panel system) including asphalt millings was installed to prevent puncturing the landfill cap. |
| Transfer station (TS) | The TS building was green building certified and an active GCCS was installed below the TS to intercept migrated LFG. |
| Side slopes (12.0 acres) | Side slopes were formed at 4:1 to 3:1 ratios with an evapotranspiration cover system to decrease rain infiltration. |
| Stormwater and erosion | Terraced berms, riprap down chutes, and sloping the landfill plateau by approximately 4% were methods used to accommodate drainage and prevent erosion. |
| Gas collection | Gas is passively vented since the total waste mass landfilled is below NSPS LFG requirements and dry climatic conditions are not likely to produce excessive LFG. |
| Groundwater monitoring | Unnecessary because distance to the water table is 1,200 ft below the land surface |
| Leachate detection | Because the landfill is unlined, precautionary detection piezometers were installed. |
| Geotechnical considerations | Battery storage for the PV system were located on virgin land to minimize variables related to lead acid and sodium sulfur batteries. |

# 5 Pre-Planning Waste Sites as Community Assets

As discussed in the introduction to this report, most planning for the beneficial utilization of closed landfill sites occurs after the landfill has been closed, or during the period just prior to closure. Many of the issues that must be addressed when assessing reuse options for a closed waste site would be easier to manage if thought was given to them during the earlier planning, design and operational stages of facility life. A waste site developed alongside an intended end use should allow a more efficient use of resources to transition the facility to a community asset. Such upfront planning would also likely provide opportunities that would otherwise not exist for achieving additional site benefits. With the likely long-term role of landfills for MSW management and the lessons learned from repurposing closed disposal facilities as community resources, landfill owners and their associated communities have the opportunity to plan future waste disposal facilities from the beginning for use as a community asset.

Building upon the information already presented, this final chapter of the report explores aspects of the waste site design with respect to how pre-planning a waste site with an intended reuse can benefit the community and provide effective waste management: site location, site layout, community involvement, technical design and future reuse. Not all of the approaches are currently practiced or permitted, but they are presented to challenge developers, planners, landfill owners, design engineers, regulators, and community leaders to potentially expand and explore additional future uses or approaches for managing closed or closing waste sites.

## 5.1 Location

Most landfills are located far from population centers because of concerns regarding odor, traffic, noise and environmental contamination. While siting waste management facilities in such locations may be the politically palatable course of action, other factors merit consideration when developing plans for a future community asset. The future use of some recreational activities might be enhanced if the facility were sited in a more convenient location for community use. Environmental concerns are largely addressed by following current regulatory requirements for landfills, and issues such as odor, traffic and noise can be minimized with proper planning, design and operational controls. The expenditure of some additional resources up front to make a facility more compatible with local residents and businesses could pay off later years in the creation of a facility that provides more benefit to the entire community.

Location is also important in consideration of energy and resource recovery. The feasibility or profitability of a LFG-to-energy system might be much more enhanced if the landfill were located adjacent to a specific industry or an industrial park where direct use of LFG could occur, or if a natural gas transmission line were located nearby. LFG-to-energy, solar power, and wind power would all benefit from proximity to electrical transmission infrastructure. Locating a landfill next to other industries or utilities that could benefit from co-location would increase overall asset utilization. For example, if a landfill were located near a wastewater treatment facility, the landfill's leachate could be more effectively managed and the treatment plant's biosolids could be placed in the landfill and later captured as methane and converted to energy. Manufacturing facilities that rely on recycled materials as feedstock would benefit from close proximity to the landfill, and the community would benefit from a greater diversion of materials from disposal.

## 5.2 Site Layout

A number of benefits should be achievable by planning the layout of a landfill facility with future use options in mind. Site roadways and access points should factor in desired uses, as should the location of the landfill units and their associated support infrastructure. Community use for some areas of the site might be possible much earlier if the site is configured appropriately. For example, if a portion of the site closes first and is ready be developed into a community asset (e.g., a recreational area), the site layout should allow public access to this area of the site while still providing appropriate control and limits from restricted areas of the operational part of the facility.

Planning for the location of utilities and roads that will be needed in the future should prevent costly retrofits or re-designs in later years. The landfill cells should be designed with desired final use in mind. For example, if a golf course is planned, the waste filling sequence and cell locations (and associated grades and elevations) can be constructed in a manner to minimize the volume of soils and additional materials that will be required, and lessen the degree of infrastructure modification needed (e.g., relocated gas and leachate lines). If solar or wind power is desired, waste cells should be placed in an optimum configuration to capture these resources. If buildings are to be constructed, specific areas may require more soil fill, or wastes less likely to settle (e.g., brick, rubble, ash) could be disposed of in that location.

The location of leachate and gas infrastructure should be located with final site configuration in mind. At some landfill locations, desired site uses have been limited because expensive reconfiguration and movement of leachate and gas infrastructure have been required.

## 5.3 Community Involvement

Allowing the input on potential utilization options, particularly at the planning phase, is another way to expand the potential scope of possibilities, and potentially source innovative ideas (similar to the idea of crowd-funding). This concept was illustrated several of the case studies reviewed in this report, where municipalities involved residents in evaluating use options after the landfill closed. Extending this to the entire life of a waste management facility, the community should be integrated into the decision-making process with regard to use of the site after closure. The community needs to be involved early in the decision process and kept informed through the operation of facility, especially as important milestones are reached. Key players and partners should be identified. Such outreach could result in finding partners that would actively participate in a true integrated materials management hub (e.g., industry, manufacturers, recyclers, end users). Advice from the regulatory agency community should be sought early and often to avoid future conflicts or unforeseen limitations.

## 5.4 Technical Design

Retrofitting closed landfills to accommodate desired end uses involves addressing complicated issues of settlement, LFG migration and leachate generation. A site that is able to control these aspects at an earlier time in the life of the site instead of waiting until the landfill has been built out, is more likely to avoid costly long-term maintenance repairs and monitoring costs. For instance, a building on top of a landfill with stabilized waste is less prone to suffer from settlement issues and structural damage. The facility will have to deal with less concern with regard to LFG migration into enclosed spaces over the life of the building.

A bioreactor landfill is an MSW landfill that is designed and operated in a manner to promote the stabilization of the waste. Components such as food waste, yard trash, and paper biodegrade in a landfill (which produces LFG and causes settlement). This process can occur slowly over many decades and thus presents operational problems many years after closure. Experience has shown, however, that if the landfill is operated under certain conditions, the rate of waste stabilization can be greatly enhanced. The most common approach used at bioreactor landfills is to add liquids to the waste, either leachate collected from the LCRS, or some other source of moisture. Some facilities also practice the addition of air in the same fashion as is done with a compost pile. While the implementation of bioreactor technology requires careful planning and implementation to make sure that it is performed in a manner that meets all of environmental protection objectives of the landfill, it can provide for landfills with much fewer problems with LFG and waste settlement in the years after closure when the landfill will be most used as a community asset.

The site developer has many options to better integrate LFG management into waste asset planning. Many landfill designers make the mistake of not considering future LFG collection as part of the original design and construction of the landfill liner system. By implementing aggressive practices for collecting LFG, more gas can be collected earlier in the life of the site, thus making gas recovery economics more feasible and reducing sources of odor and related emissions. For example, the GCCS can be integrated into the LCRS (which is often a significant source of LFG) early on in the construction of a landfill. Innovative practices such as exposure geomembrane caps can allow greater gas collection efficiency earlier in the life of the landfill. The GCCS can be readily designed to accommodate a variety of future landfill configurations and uses, and thus potential impacts on GCCS infrastructure (a common issue observed in the case studies) can be minimized. The GCCS can be designed to avoid interference with the aesthetics of the site or get in the way of the end use (e.g., gas wells sticking out of a landfill golf course).

## 5.5 Planning for Future Recovery

Depending on a variety of factors (e.g., poor market, prohibitive distance to recycler), there may instances when a landfill facility does not have the means to recycle or use a waste product, but has the foresight to plan for the future recovery of the material at time when it is more economically viable. Materials that are accepted in bulk and arrive at a disposal facility separate of other waste materials (e.g., water treatment sludge, concrete) are candidate materials for future recycling or beneficial use applications because of their large quantity which can make their recovery more economical and because the waste does not have to be sorted which avoids the additional expense of processing.

Facilities that identify a material as a potential future commodity and prepare and design their landfill filling around recovering these materials at a later day in the future, position themselves to take advantage of situations that may improve recycling circumstances. Ideally, the facility employing such a strategy would set aside a portion of the landfill and dedicate it solely to this particular material so as not to blend it with other contaminants that would depreciate its value. The location of the material must be accurately documented to avoid disturbing areas unnecessarily and tracking the quantity of material is essential in determining the right time at which there is sufficient material that has accumulated and the economics of excavating and recovering the material is justified. This type of approach is already common at landfills that accept special wastes such as asbestos, so basic principles and practices for dedicated disposal areas of likely (or potentially) higher-value materials would not be an unknown to many site owners and operators. Reclaiming waste materials increases available landfill air space, it can be an additional source of revenue for the facility and the environmental advantages of recycling/reusing waste materials are all potential benefits of planning the future recovery of waste materials.

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# 7 Appendix A

## *7.1 Resources for Further Reading*

| Resource | Description |
|---|---|
| FDEP (2011). Guidance for Disturbance and Use of Old Closed Landfills or Waste Disposal Areas in Florida. Department of Environmental Protection Solid Waste Section, Tallahassee, FL<br><br>http://www.dep.state.fl.us/waste/quick_topics/publications/shw/solid_waste/Dump-Guidance-03Feb11.pdf | Describes the expectations of the Florida Department of Environmental Protection when an old site is disturbed or used including when construction is to occur near or over waste-filled areas. Provides Department contact information; summary of landfill permit, closure and long-term care requirements; |
| Martin, W. L., and Tedder, R. B. (2002). Use of Old Landfills in Florida. Proceedings of the 16th GRI Conference, Geosynthetic Institute Philadelphia, PA, USA, December 16-17, 2002.<br><br>http://www.dep.state.fl.us/waste/quick_topics/publications/shw/solid_waste/USEOFOLDLFsINFL-totalPaper.pdf | Four case studies of landfill use in Florida (all projects included construction over or near the landfill) and the lessons learned from their experiences. |
| IDEM (1999). Post-Closure Uses of Solid Waste Disposal Facilities. Indiana Department of Environmental Management Office of Land Quality, Indianapolis, IN, WASTE-0026-NPD.<br><br>http://www.in.gov/idem/files/nrpd_waste-0026.pdf | Guidance document developed by Indiana Department of Environmental Management for the beneficial post-closure use of landfill including agricultural, recreational and industrial activities. |
| MassDEP (2009) Landfill Post-Closure Use Permitting Guidelines June 2009. Massachusetts Department of Environmental Protection.<br><br>http://www.mass.gov/eea/agencies/massdep/recycle/approvals/landfill-post-closure-use-permitting-guidelines.html (website)<br><br>http://www.mass.gov/eea/docs/dep/recycle/laws/lfpcguid.pdf (document) | The Massachusetts permitting process and requirements (for facilities that have not obtained previous permits or permissions for the end use) for major and minor post-closure uses. |
| NJDEP (2014) Guidance Documents. http://www.nj.gov/dep/sage/so- | New Jersey guidance documents that discuss determining sites best |

| Resource | Description |
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| guidancedocs.html Accessed 16 April 2014.<br><br>NJDEP (2012) Solar Siting Analysis. New Jersey Department of Environmental Protection Sustainability and Green Energy, October 2012.<br><br>NJDEP (2013) Guidance for Installation of Solar Renewable Energy Systems on Landfills in New Jersey (Updated January 8, 2013). New Jersey Department of Environmental Protection. | suited for developing solar energy projects and how to apply for permits, permissions and the issues with installing a solar renewable energy system on a landfill. |
| Ohio EPA (2010). Considerations for Development On or Adjacent to a Closed Solid Waste Landfill. Ohio EPA, Division of Solid and Infectious Waste Management, Columbus, Ohio, Guidance Document 1003, March 2010.<br><br>http://www.epa.ohio.gov/portals/34/document/guidance/gd_1003.pdf | Ohio Environmental Protection Agency discusses environmental considerations when developing on or adjacent to a closed solid waste landfill. |
| TCEQ (2014) Use of Land Over Closed Municipal Solid Waste Landfills. Texas Commission on Environmental Quality, https://www.tceq.texas.gov/permitting/waste_permits/msw_permits/msw_closeduse.html Accessed 16 April 2014. | The state of Texas' applicable regulations; application procedures for permitting or registration for development of land over a closed MSW landfill (2005); questions and answers for developing on land over an MSW landfill (2010). |
| US EPA (2005) Guidance for evaluating landfill gas emissions from closed or abandoned facilities. EPA -600/R-05/123a, September 2005.<br><br>http://www.epa.gov/nrmrl/pubs/600r05123.html | A guidance document for superfund remedial project managers that provides background information relevant to closed MSW landfills including: LFG basics, exposure risks and problems and LFG collection and control systems. |
| US EPA and NREL (2013) Best Practices for Siting Solar Photovoltaics on Municipal Solid Waste Landfills. NREL/TP-7A30-52615, February 2013.<br><br>http://www.epa.gov/oswercpa/docs/best_practices_siting_solar_photovoltaic_final.pdf | A technical guidance document addressing challenges of siting photovoltaics (PV) on MSW landfills. Discusses the types of PV technology and considerations related to feasibility, design, construction, and operation and maintenance of PV. Includes a summary of best practices for siting PV. |
| US EPA (2014) Handbook on Siting Renewable Energy Projects While | Discusses reusing contaminated sites for renewable energy projects and |

| Resource | Description |
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| Addressing Environmental Issues. U.S. Environmental Protection Agency Office of Solid Waste and Emergency Response's Center for Program Analysis, http://www.epa.gov/oswercpa/docs/handbook_siting_repowering_projects.pdf Accessed 16 April 2014. | includes evaluating the renewable energy potential of a site and integrating renewable energy development into cleanup processes. |
| US EPA and NREL (2014) Screening Sites for Solar PV Potential. http://www.epa.gov/oswercpa/docs/solar_decision_tree.pdf Accessed 16 April 2014. | This document is a decision tree to assist state and local governments and stakeholders screen sites (including landfills) for redevelopment with solar PV energy. The document describes the processes of pre-screening, site screening and financial screening. |
| US EPA and NREL (2014) Screening Sites for Wind Energy Potential. http://www.epa.gov/oswercpa/docs/wind_decision_tree.pdf Accessed 16 April 2014. | This document is a decision tree to assist state and local governments and stakeholders screen sites (including landfills) for redevelopment with wind energy. The document describes the processes of pre-screening, site screening and financial screening. |
| US EPA (1997) Landfill Reclamation. Solid Waste and Emergency Response, EPA530-F-97-001, July 1997.<br><br>http://www.epa.gov/osw/nonhaz/municipal/landfill/land-rcl.pdf | This document describes the basics of the reclamation process and project planning and also touches on its benefits and drawbacks and provides case studies of successful projects. |
| US EPA (2001) Reusing Superfund Sites: Recreational Use of Land Above Hazardous Waste Containment Areas<br><br>http://www.epa.gov/superfund/programs/recycle/pdf/recreuse.pdf | This document describes the technical considerations of designing recreational facilities as superfund cleanups where some of the hazardous waste is retained on site; case studies of successful projects are included. |
| US EPA (2003) Reusing Cleaned Up Superfund Sites: Golf Facilities Where Waste is Left on Site<br><br>http://www.epa.gov/superfund/programs/recycle/pdf/golf.pdf | This document describes the elements of planning, designing, operations and maintenance related to developing a golf course facility on a superfund site; case studies of successful projects are included. |
| US EPA (2002) Reusing Superfund Sites: Commercial Use Where Waste is Left on Site | This document describes site configurations, remediation approaches, and design considerations when planning to reuse a superfund site for commercial purposes; case studies of successful projects are included. |

| Resource | Description |
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| http://www.epa.gov/superfund/programs/recycle/pdf/c_reuse.pdf | |