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Sustainability and Waste Management: Case Histories

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SUSTAINABILITY AND WASTE MANAGEMENT: CASE HISTORIES

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ABSTRACT

Sustainability is the condition of maintaining a process or a state at a certain level for perpetuity. In waste management and geoenvironmental engineering terms: sustainability is making marginal and waste lands and waste products into usable properties, products and services. To address sustainability issue, this paper first presents waste minimization policies prior to disposal; a few examples of this are: recycling, composting and incineration. After efficiently using the waste minimization policies, the remaining produced waste needs to be disposed of which has two aspects (i) the presently active waste disposal sites and (ii) the already disposed waste and closed waste sites. Active sites can be made sustainable by using techniques, such as, optimizing the airspace within the permitted boundaries by using MSE Berm, using bioreactors and utilizing landfill gas (LFG) for energy generation. The closed sites can be made "more sustainable" by developments, such as, parks, golf courses, industrial and commercial buildings, and solar and wind power generation projects. Finally, there are a few incubator technologies that, at the present time, are at pilot scale levels and work on them needs to be actively encouraged so that the advancement in sustainable technologies is continued. A few examples of such technologies are: Plasma arc, converting hard to recycle plastics into diesel and gasoline, and energy parks. This paper discusses these issues and presents case histories that help sustainability. The case histories presented consist of MSE berm and bioreactor technologies at active waste disposal sites; and industrial and commercial buildings and solar energy projects constructed on top of already closed landfills. All these cited case histories exhibit that by using existing technologies greenhouse gases (GHGs) and carbon footprint can be reduced resulting in the maintenance of sustainability.

INTRODUCTION

The topics of sustainability and waste management are the two most important issues that our twenty first century industrial/high technology society has rightly recognized. We are fortunate that now we are taking steps to effectively deal with these issues. Actually, some thinkers are of the opinion that these issues are at the very heart of our survival, i.e., our very survivability depends on how we effectively deal with these two issues. President Bill Clinton in an article, in 2012, entitled, The Case for Optimism, wrote that "there are three big challenges with our interdependent world: inequality, instability and unsustainability." From sustainability view point, it is important to know that the way we consume our limited resources and the way we produce our waste are currently unsustainable. Eventually, if left the way it is going, this may cast shadow over our children's future. Therefore, we have to understand the causes and effects of this and then mend our ways so as to reverse the trend. Based on this authors understanding of the current research and development trend, the indications are that we can do this.

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Sustainability: General

The term sustainability has been used, overused and in some cases misused recently. In simple terms, it is the permanency of geoengineering system, i.e., our air, water, ground and the overall ecosystem system surrounding our planet. Sustainability can be described as a condition of maintaining a process or a state at a certain level for perpetuity. In environmental terms it refers to maintaining the longevity of "human-ecological support system". A few examples for this in relation to the resource system maintenance are: agriculture, fisheries, industry, climate system, water and other resources that are needed for the maintenance of healthy human communities. This means that from human health and environment perspective we would prefer to have a sustainable productive system indefinitely. That is why we need to consider anthropogenic (effects due to human activities)[2] factors, such as, climate change, depletion of fossil fuel reserves, loss of forest reserves, shortage of water resources and other anthropogenic problems. All this can be summarized in the words of Brundtland Commission[3] which defined sustainable development that "meets the needs of the present without compromising the ability of future generations to meet their own needs"[4]. However, as we know in practical terms nothing is absolute, i. e., there is no system that can be maintained indefinitely. Therefore the terms used as "more sustainable" or "less sustainable" are more practical terms and should be used instead of the term sustainable. For example when we talk about "energy saving compact florescent light bulbs might be considered more sustainable than incandescent ones, and so forth"[5]

Many methods of sustainability measurements have been developed; description of these is beyond the scope of this text; therefore not discussed here. In author's opinion The "Daly Rules"[6] provide useful operational rules to define the condition of sustainability; these rules are:
"(i) Renewable resources such as fish, soil, and groundwater must be used no faster than the rate at which they regenerate, (ii) Nonrenewable resources such as minerals and fossil fuels must be used no faster than renewable substitutes for them can be put into place, and (ii) Pollution and waste must be emitted no faster than natural systems can absorb them, recycle them, or render them harmless." Actually Brundtland provides the ethical goal of non-depletion of natural capital while Daly Rules provide the operational phase of the goal in physical terms. Therefore both Brundtland and the "Daly Rules" are complementary to one another. [7] Sharma (2008) presents these and other issues related to sustainability.

Sustainability: Geotechnical and Waste Management Perspectives

So, in general, sustainability can be described as a condition of maintaining a process or a state at a certain level for perpetuity. In Geotechnical and environmental (especially Geoenvironmental) engineering terms, it refers to maintaining the longevity of "human-ecological support system". From waste management perspective, consumption of resources in any production system needs to be recovered so as to have a sustainable productive system. In other words, pollution emitted and waste produced must be no faster than natural systems can absorb them, recycle them, or render them harmless.

Specifically, sustainability in geotechnical and waste management points of view would mean that:

- **Geotechnical Perspective:** (i) make marginal/wasted land areas usable by constructing foundations for building structures on top of them. A few examples of these so called wasted areas may be: closed old landfills, waste lands, wet lands etc., and (ii) make waste and /or recycled products marketable and reusable, such as, ash, tires, concrete rubbles, plastics, glass etc. These products can be used as aggregates, drainage layers, road subgrades etc. This, of course would need further product development oriented R & D.

- **Waste Management Perspective:** (i) Remediation of polluted sites: practical utilization of existing research data and conduct new R & D, such as, bioremediation, phytoremediation, pump & treat, vapor extraction, encapsulation etc., and (ii) Optimize the active disposal site uses: Bioreactors, liquefied LFG, Landfill Gas to Energy etc., and (iii) End uses of the Closed and Remediated sites: Construct commercial and industrial buildings, parks, golf courses and energy generation facilities, e.g., solar panels and wind energy generation systems on marginal lands.

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[2] This means the effects derived from human activities as opposed to happening due to natural causes without human influences.
[3] This commission was led by the former Norwegian Prime Minister Gro Harlem Brundtland.
[4] United Nations (1987)
[5] http://en.wikipedia.org/wiki/Sustainability
[6] Rules suggested by Professor Herman E. Daly of the University of Maryland School of Public Policy and former Chief Economist of the World Bank.
[7] http://en.wikipedia.org/wiki/Sustainability

From waste management point of view, sustainability may mean that the pollution and waste may be produced and disposed of no faster than the natural system can absorb them, recycle them, or render them harmless. So, sustainability, in relation to waste management, would require, among others, the following:

- Minimize waste generation,
- Recycle the generated waste,
- Optimize the use of disposal areas, and
- Optimize the post disposal areas uses.

Recently, there has been great awareness on waste recycling and is being carried out enthusiastically over the past few decades. However, even with waste recycling, which depends on their end use and economics, there still is a significant amount of waste that will need to be disposed of.

Figure 1 presents sustainability strategies that can be used for the (i) Waste minimization prior to disposal, (ii) Active site where the waste is currently being disposed of, (iii) Waste disposal sites that have been closed, and (iv) Certain waste related incubator technologies.

Waste Minimization prior to Disposal requires both the public education and policy issues. This should start with policies, such as, (i) public education, (ii) recycling, (iii) composting and (iv) incineration. Public education means making public aware of the importance of producing minimal amount of waste as much as possible. Policy issues consist of encouraging recycling, composting and incineration prior to taking the waste to the disposal sites.

According to US EPA, "In 2010, Americans generated about 250 million tons of trash and recycled and composted over 85 million tons of this material, equivalent to a 34.1 % recycling rate." As a comparison the recycle rate was only about 17 % in 1980. So, there has been a 100% increase in recycling rate between 1980 and 2010. Recycled materials, such as, paper, glass, plastics and metals reduce the need for new raw materials and the compost end product can be used as a natural fertilizer. Recycling[8] and composting[9] , thus, contribute to sustainability. However, in 2010, still about 165 million tons of waste was still needed landfilling. Therefore, we, as a society, need to devise means to make the waste disposal methods/techniques more sustainable. One such technique, called incineration, where combustion of MSW is being used to generate energy, is currently being used in the US at 86 facilities. According to US EPA, although no new facilities have been built since 1995, the current facilities have the capacity to produce about 2,700 megawatts of power per year by processing about 30 million tons of waste per year.

After utilizing methods to minimize waste prior to disposal have been executed the remaining waste needs to be disposed of at the landfills. This brings us to the subject of techniques/methods to be used so that the **Active Disposal Sites** become sustainable. The methods that can make them sustainable are the techniques like: optimize the airspace within the permitted boundaries, bioreactors and landfill gas (LFG) to energy projects. Case histories for the first two of these techniques will be presented here. Once these sites have achieved their permitted footprint and heights they will need to be closed. The sustainability will then require that these **Closed Sites** do not remain as a wasted land but be put to beneficial use. A few such uses are: parks, golf courses, buildings, solar and wind power facilities. In this paper we will present case histories of utilizing such closed sites for buildings and solar power generation.

Lastly, it is also important to note that, currently, there are a number of innovative techniques that are being developed by the researchers which could become commercially viable within a decade or so; we can call them as **Incubators**. To name a few of these

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[8] Recycling is the recovery of useful materials, such as, paper, glass, plastic, and metals, from the trash to make new products. This, thus, reduces the amount of new raw materials needed.
[9] Composting involves collecting organic waste, such as, food scraps and yard trimmings, and storing it under conditions designed to help it break down naturally. This resulting compost can then be used as a natural fertilizer.

are: (i) Plasma arc: Plasma arc technique, which particularly suitable for hazardous and radioactive wastes, is now being used for MSW as well. This technology is turning MSW into clean green, renewable fuel in the form of synthetic gas (SynGas) and the toxic materials left become encapsulated (in the form of glass) and can be disposed in a safe manner[10]. A pilot scale project is already in operations at the 700-acre Columbia Ridge Landfill in Arlington, Oregon (Wolman, 2012). Another innovative technology, currently in pilot scale production in North Portland by Waste Management, is The Agilyx Technology. In this technology, the difficult-to-recycle plastics and contaminated plastics are being converted into ultra-low sulfur diesel, gasoline and even new plastics. The technology is "anaerobic thermal reclamation," which uses an oxygen-free chamber and heat to process plastics that are made of mixed resins and may be dirty or greasy Waste Management, 2012). An integrated sustainable development at an existing waste disposable site can be achieved by using more than one of these technologies at one site; such a development can be named "Renewable Energy Park". This is being forwarded at a few sites and actually being used at some sites without being called as such. This consists of using solar, wind, methane, and even geothermal technologies to generate energy.

This paper first presents a case history where sustainability concept was misapplied without considering its adverse impact on the protection of human health and the environment. Following this, sustainability related case histories on constructing MSE berm and Bioreactor at active landfill sites, buildings and solar power projects over closed landfills are presented. Discussions on how the projects are helpful in reducing the carbon footprint and also having an environmentally sustainable development are also presented in the text.

SUSTAINABILITY WITHOUT ENVIRONMENTAL HEALTH CONSIDERATIONS

As is well known, between 1942 and 1953, over 20,000 tons of chemical waste was disposed in an abandoned canal (Love Canal near Niagara Falls in New York) by a chemical manufacturing company. Figure 2 shows the site in 1952. Niagara School Board purchased this property; some buildings of a school were built on top of the waste filled areas and the school was opened in 1955. Subsequent residential development followed and by 1972 several homes with basements were built in the areas surrounding the school (See Figure 3). Heavy rainfall, in 1976, caused the groundwater to raise causing subsidence of the waste fill area resulting in contamination of the surface water. Seepage of groundwater transported toxic chemicals into the basements of the surrounding homes. The contamination was discovered when, in 1977 and 1978, children in the area fell sick and other health issues were noticed. The Love Canal area was subsequently evacuated and a state of emergency was declared. Since that time extensive remedial measures have been undertaken at the site (Sharma and Reddy, 2004). Figure 4 shows the remediated site in 2006.

Initially, the waste was disposed in the abandoned canal by utilizing an unused property for waste disposal. However, at a later date, in spite of warnings the area was developed for residential purposes with a view of putting the abandoned land to "good" use. This is a bad example of sustainability concept; this completely ignored environmental health considerations, resulting in major human health costs that could have been avoided.

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[10] Plasma arc is the fourth state of matter (the other three being solid, liquid, and gas) which is an ionized gas; like the one exists in nature during the lightning. Actually, much of the universe exists in plasma state (Electronics for you, January 2009: www.EFYMAG.com).

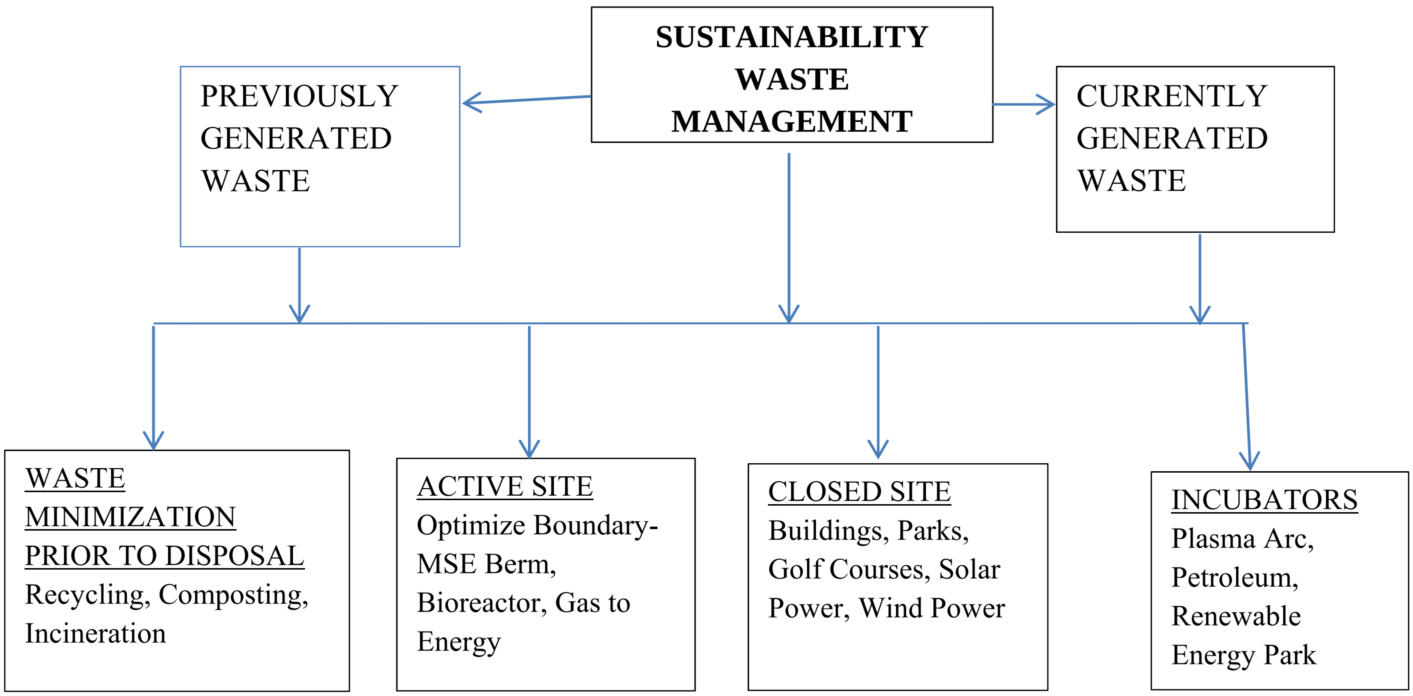

Figure 1 Sustainability Relative to Waste Management Sharma (2012)

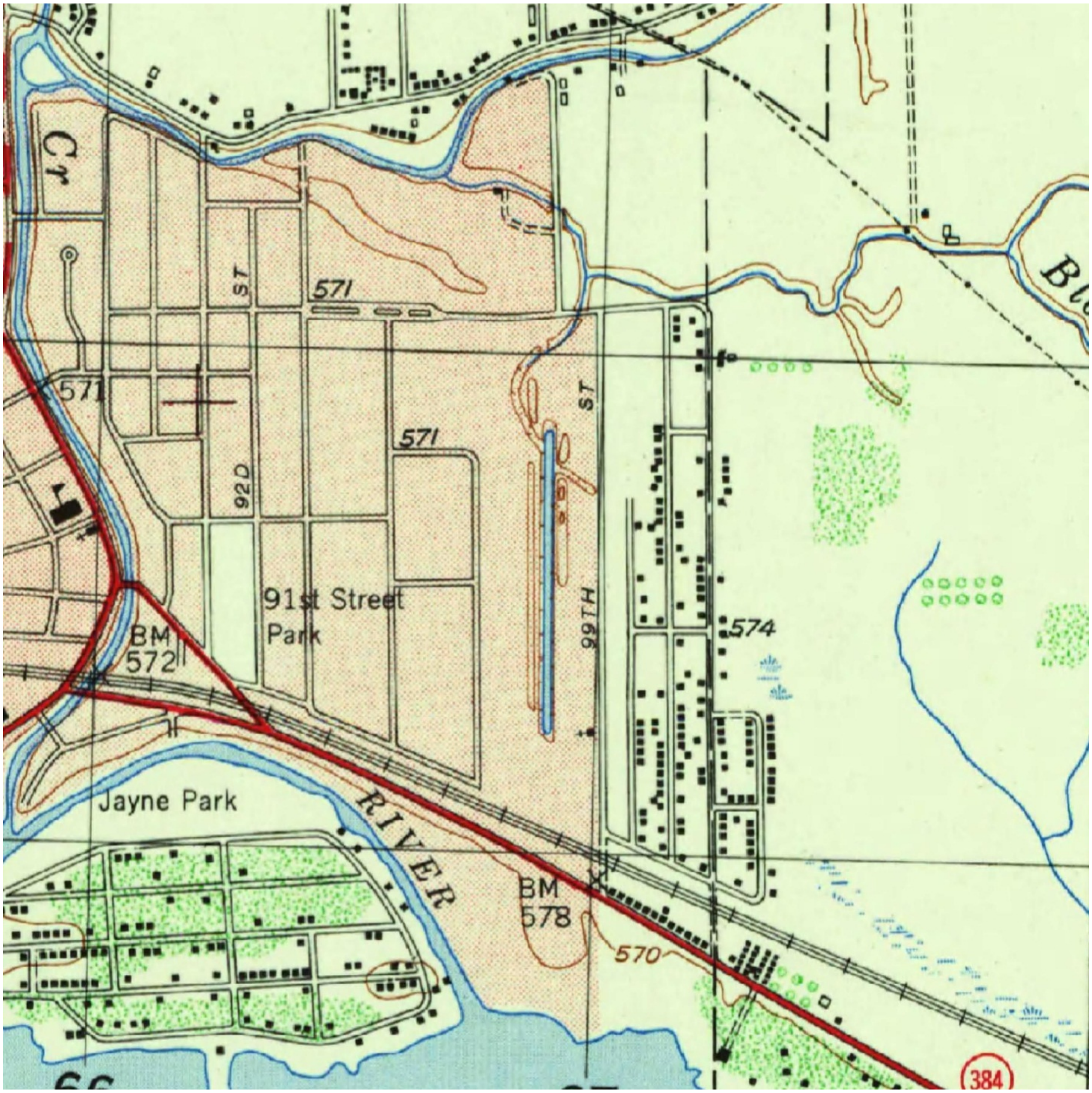

Figure 2 Love Canal Site in 1952: Chemical Waste Disposed of in an Abandoned in Canal (Sharma, 2012)

Figure 3 Love Canal Site in 1972: A School and Residential Development at the Site (Sharma,2012)

Figure 4 Love Canal Site in 2006: After Extensive Remedial Action Taken at the Site (Sharma, 2012)

WASTE CURRENTLY BEING DISPOSED AND THE SITE IS ACTIVE

It is well known that nobody wants waste in their neighborhood – "Not in MY Backyard" (NIMBY) syndrome; this makes siting new waste facilities very difficult. This means the operators of existing waste facilities would try to optimize the facility air space within the already permitted boundaries and use available waste resources to their fullest extent. The two cases we will discussed here, to achieve this goal are: (i) Using Mechanically Stabilized Earthen (MSE) Berm, and (ii) Bioreactor. These are discussed below.

Mechanically stabilized Earthen (MSE) Berm

MSE berm technology consists of utilizing geosynthetics in combination with soil to create a safe and cost-effective system that creates usable airspace within a given permitted footprint. Figures 5 present a comparison between a conventional (traditional) earthen berm and an MSE berm to create additional airspace within the permitted waste boundary. As is evident an MSE berm optimizes the airspace within the boundary limits.

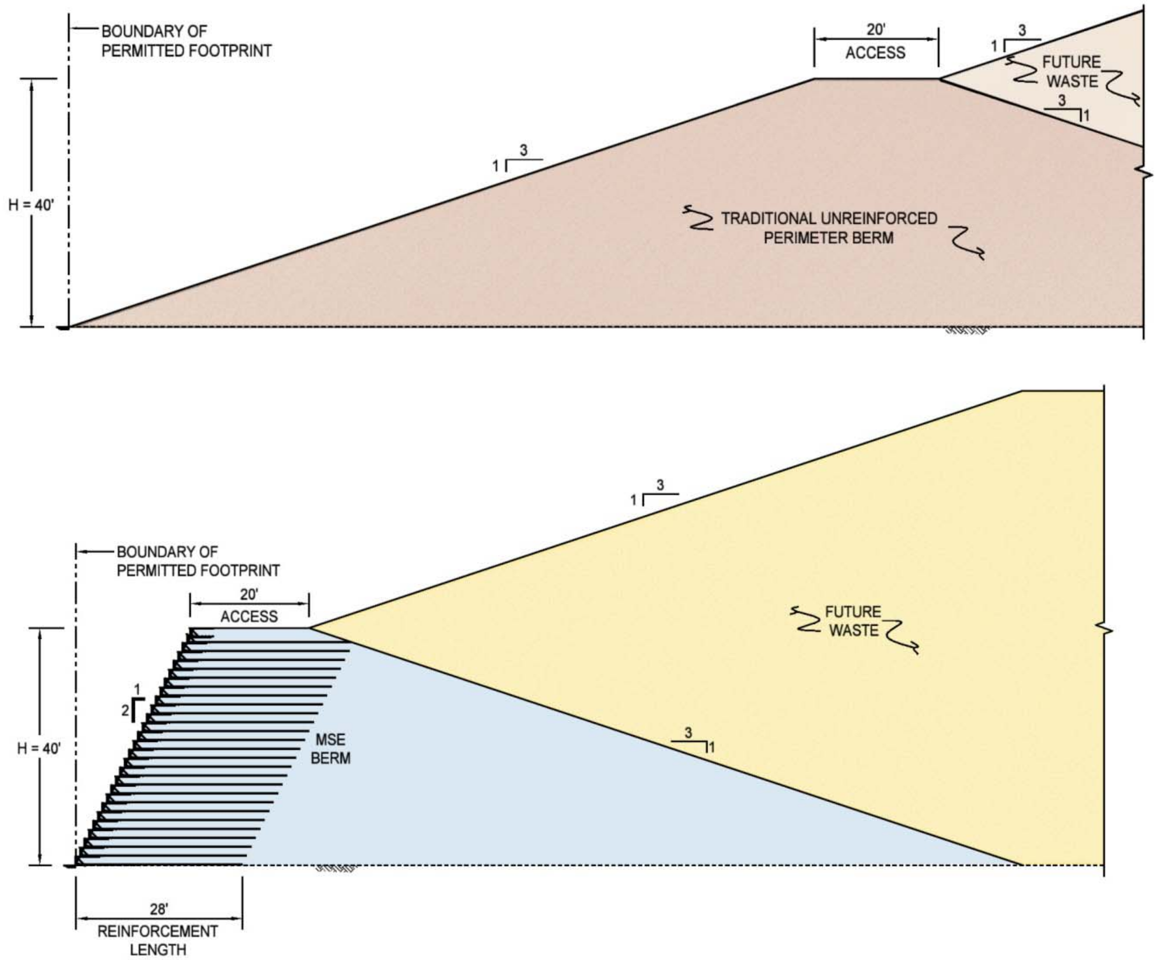

Figure 5 Comparison of Traditional Berm and MSE Berm within the Permitted Boundary (Brown and Liew, 2012)

Additionally, MSE berm construction also minimizes the carbon footprint[11]. This is further discussed below. MSE berm technology using geosynthetics was introduced in Waste containment in US market in 1996. Since then a large number of such facilities have been constructed. One such an example is Cherry Island landfill vertical expansion project presented below.

Cherry Island Landfill MSE Berm Example

Cherry Island municipal solid waste facility is located in Wilmington, Delaware, where waste has been disposed since 1985. The facility is located at the confluence of the Delaware and Christina rivers. The subsurface conditions consist of about 40 feet thick dredged materials overlying about 45 feet thick alluvial deposit which then is underlain by medium dense to dense residual sand layer.

[11] Carbon footprint is the total set of greenhouse gas (GHG) emissions caused by an organization, event, product or person. The GHG is a gas in an atmosphere that absorbs and emits radiation within the thermal infrared range. The primary GHGs in the Earth's atmosphere are water vapor, carbon dioxide, methane, nitrous oxide and ozone. These gases greatly affect the earth's temperature and hence the hence many natural activities, like weather.

The soft subsurface conditions require that the landfill slope could not be steeper than 8 horizontal to 1 vertical slope. Based on the waste disposal estimates, in early 2000s, it was realized that this facility needed expansion which could not be done in lateral directions. Therefore, the optimal solution was to expand vertically. After a review of the site conditions, it was concluded that ground improvement and mechanically stabilized earthen (MSE) berm combination would the best solution for the expansion project.

The underlying foundation soils had about 60 to 100 feet of thick weak, low permeability soils with undrained shear strength of about 200 pounds per square feet (psf). The evaluation required constructing about 70 feet high perimeter MSE berm. Since the foundations were soft a ground improvement technique was required to construct this perimeter berm. After evaluating various ground improvement techniques, such as, deep soil mixing, sand drains and prefabricated vertical wick drains (PVDs), the PVDs system was selected for ground improvement so that the perimeter MSE berm can be constructed over it. The MSE berm was constructed in stages so that the foundation soils get strengthened by getting consolidated under the phased constructed MSE berm. Thus the berm played the dual role: (i) it compressed and consolidated the foundation soils, and (ii) at the same time provided new disposal space. The time dependent consolidation was achieved by the drainage paths provided by Nilex PVDs (wick drains) which drained water from the dredged alluvial material to the underlying sand deposits. Piezometers were used to measure the excess pore pressure dissipation rate as the MSE berm was constructed in phases. The design engineering firm was Geosyntec Consultants. The geosynthetic materials were Mirafi PET 1170 (a high strength woven polyester geotextile) for the bottom two layers for soil reinforcement, the geogrid consisted of PET Miragrid 20XT coated with PVC, Miramesh GR (the biaxial geogrid for the vegetation at the front of the wire basket). The construction started in fall 2006 and completed in spring 2011. Figure 6 shows the landfill liner installation behind the MSE berm and Figure 7 shows the overall MSE berm configuration.

Contribution to Sustainability by MSE Berm Construction (In terms of carbon footprint reduction)

A few factors that can contribute to sustainability by construction of MSE berm in waste facility are: (i) elimination or delay in need to site and construct a new facility, (ii) reduction in time and resources required to construct a given containment berm configuration, and (iii) vegetated MSE berm face, if used. Although quantification of carbon footprint reduction can be complicated, however a simplified calculation can be made by considering: (i) the materials and their transportation to construct a traditional 3H: 1V berm slopes which requires select backfill to be transported and backfilled, (ii) 0.5H: 1V MSE berm exterior side slope, (iii) construction of new landfill in lieu of a 40-foot high MSE berm, and (iv) the liner materials are the same between two options. Figure 8 shows how containment berm footprint is minimized and Figure 9 shows a flow chart comparing the carbon footprint of MSE berm and traditional berm. The evaluation results show that considering materials and transportation only, construction traditional perimeter berm will be about 200 $kgCO_2$ while for a MSE berm it is about 134 $kgCO_2$. This means there is a 33% reduction in carbon footprint using MSE berm as compared with constructing a traditional unreinforced MSE berm (Brown and Liew, 2012). The additional benefits of MSE berm in sustainability by using solar panels on top of additional slopes and top deck created by MSE berm, as discussed will be later.

Figure 6 Landfill Liner Installation behind the MSE Berm (Geosyntec, 2012)

Figure 7 shows the Overall MSE Berm Configuration (Geosyntec, 2012)

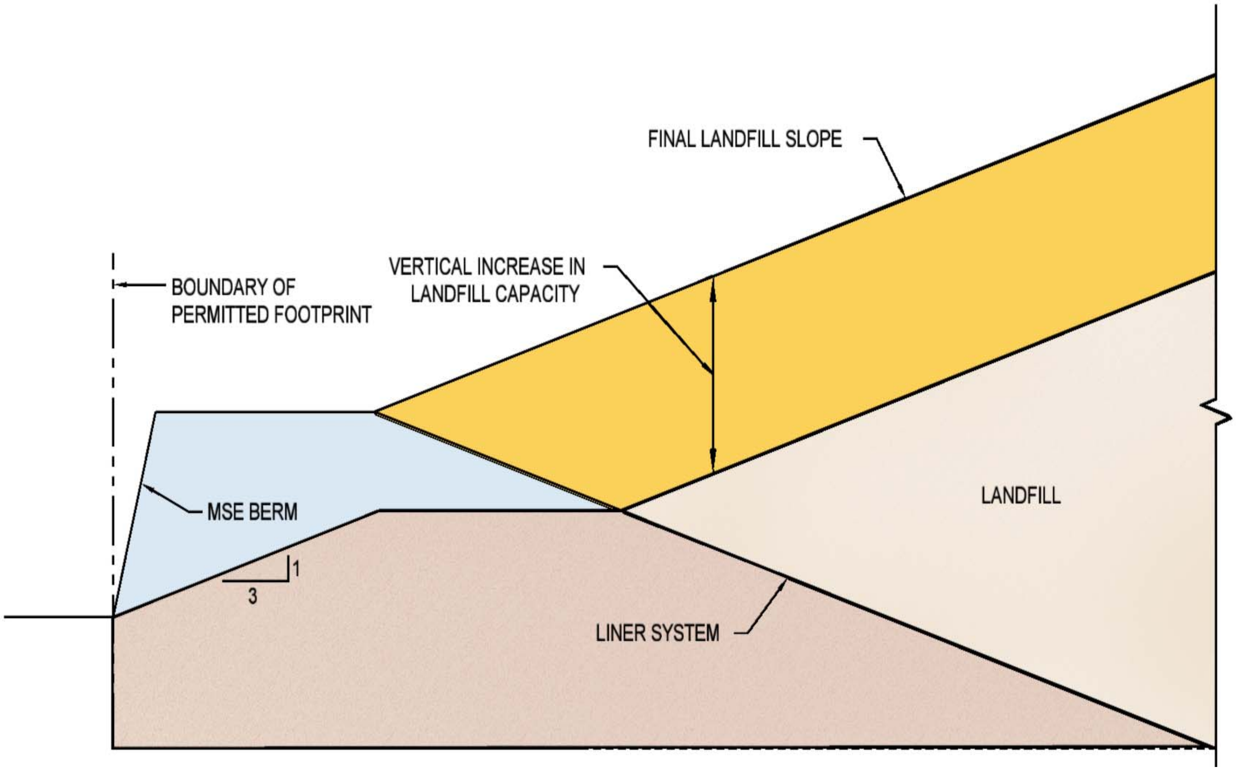

Figure 8 Reduction in Containment Berm Footprint: MSE Berm (Brown and Liew, 2012)

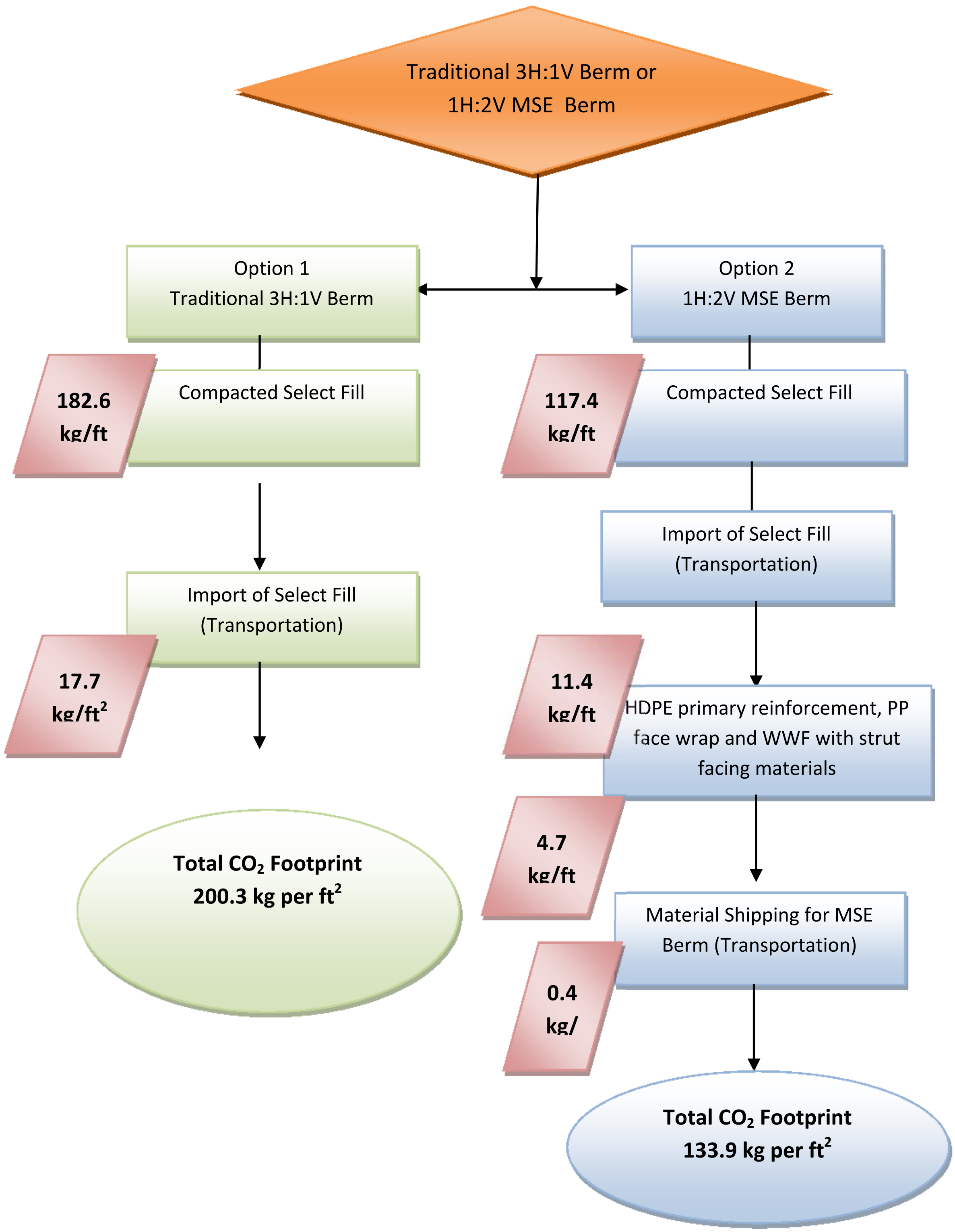

Figure 9 Comparing the carbon Footprint of Traditional Berm and MSE Berm (Brown and Liew, 2012)

Bioreactor

The conventional municipal solid waste landfill (MSW) design is geared to place a base lining system at landfill bottom and a cover lining system at top after the landfill has achieved its design grades. This is aimed at restricting the surface water to infiltrate into the waste and collecting any leachate generated above the base liner by a leachate collection system. This slows down the waste degradation in the landfill. On other hand a bioreactor landfill is designed and operated to enhance microbial activity resulting in accelerating organic waste degradation

Within 5 to 10 years (USEPA, 2012, and Sharma and Reddy, 2004). In a bioreactor landfill, liquid is added until the field capacity[12] of the waste is reached and as the leachate drains from the waste it is collected at the bottom and recirculated back into the landfill to maintain moisture throughout the waste. This process helps to distribute nutrients and contaminants throughout the landfill for microbial biodegradation. It should be noted that the available leachate quantity alone is usually not enough to sustain the bioreactor needs. Depending on the climate and regulatory approval, water or other nontoxic or nonhazardous liquids and semi liquids can be suitable amendments to supplement the leachate for efficient bio-reactions.

Bioreactor landfills can be categorized into three classes: (i) Anaerobic bioreactors – where waste degradation is accelerated by anaerobic microorganisms, (ii) Aerobic bioreactors – where aerobic microorganisms accelerate waste degradation, and (iii) Hybrid bioreactors – where aerobic and anaerobic organisms accelerate waste degradation; this system is still being investigated.

Anaerobic microorganisms do not need oxygen for cellular respiration; most landfills are naturally deficient of oxygen therefore anaerobic conditions exist in the landfills without any intervention. These microbes are responsible for conversion of organic wastes into methane and carbon dioxide. Most landfills have moisture ranging between 10 % and 20% and need addition of moisture to reach the field capacity (typically 45 to 65%). Figure 10 presents a schematic diagram showing major components of an anaerobic bioreactor including leachate/moisture addition system, gas recovery system, bottom liner system and leachate collection system.

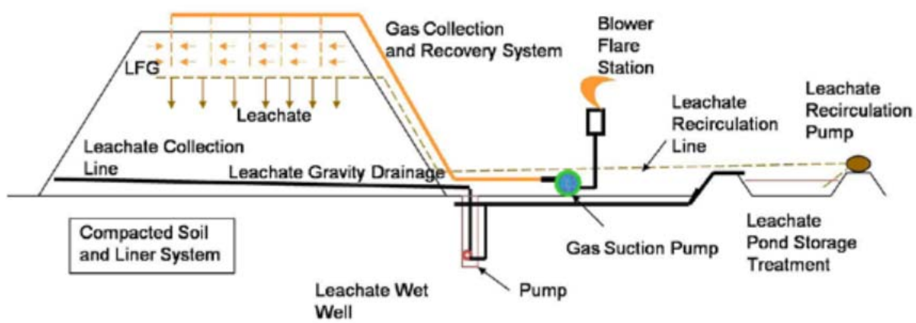

Figure 10 A Schematic of Anaerobic Bioreactor System (Townsend, et al, 2008)

Aerobic microbes require oxygen for cellular respiration to produce carbon dioxide. Since landfills are deficient of oxygen, aerobic activity is promoted by injecting air or oxygen into waste; injection of oxygen or air can be done using the same horizontal and vertical wells that are used to extract gas or inject liquid. Since aerobic microbes grow faster than anaerobic microbes, therefore, waste degrades at a faster rate than in anaerobic system.

From sustainability view point, bioreactor landfills have the following benefits.

1. Typically conventional landfill waste-stabilization time frame may take from 30 to 300 years while anaerobic waste may stabilize in about 10 to 15 years and aerobic landfill waste may stabilize within about 2 to 4 years. This means there will be shorter period of leachate and gas generation; this means a shorter time needed for environmental monitoring and control requirements.

[12] Liquid holding capacity of the waste.

2. Conventional landfills typically settle about 10% in 10 years while bioreactor landfills may settle 20% or more within that period. Therefore, bioreactor landfills will have more waste volume (airspace) capacity within the same permitted footprint; thus extending landfill life and reduced need to site new landfill
3. Methane gas generation rate is accelerated thus in some cases gas to energy or liquefied LFG projects are feasible.
4. Controllable gas yields during operation could help reduced GHG.

Yolo County Bioreactor Landfill Example

There a number of landfills sites those have been given permission to test bioreactor landfill technology[13]. The main purpose for these projects is to obtain data and information both on technical and other issues so that an informed policy decision for future bioreactor landfills can be made. At this time, there are thirteen (13) bioreactor landfills in various states in USA, one (1) is in Canada and two (2) are in Australia. Below, is presented the case history for the Yolo County Bioreactor Landfill Project located in Northern California.

The Yolo County Central Landfill in Davis, California, is a 722-acre disposal site for non-hazardous solid waste, construction debris, and no-hazardous liquid waste (such as, greases, oil, and sludge). Among existing on-site operations include a methane gas recovery and energy generation facility. Yolo County has plans for a two-phase project to operate a 20- acre project, of which a 12-acre section has already been constructed. Figure 11 shows a plan view of the bioreactor project at the site.

The 12-acre section contains one 9.5-acre anaerobically operated area and an adjacent 2.5-acre aerobically operated area (Figure 11). Horizontal gas wells have been constructed in both (anaerobic and aerobic cells) these cells. The extraction system is designed to lower the levels of methane that normally would have emitted to the atmosphere. Depending on the results of first phase, the second phase of this 20-acre project will be completed. Figure 12 shows a photograph of the completed first phase of this project. Extensive instrumentation included temperature, moisture, and static head over the base liner, and liquid pore pressure measurements have been performed at the site. A summary of a few key results indicate that:

1. Elevated internal cell temperatures: 45 to 60 degrees Celsius (5 to 15 degrees higher than conventional cell temperatures),
2. Leachate levels over the base liner: observed heads about 2 inches,
3. LFG composition and recovery: Methane content from the recovered gas in both the anaerobic cells quickly reached 50 % within three months after leachate addition stated; in conventional cells it may take a lot longer to achieve such methane production rate and depends on, among other factors, initial waste moisture content, waste character, operation methods, and weather conditions. This methane content is eminently suitable for fueling power generation.
4. Settlement and volume loss: Although, for this project, it is a little early to quantify the total volume reduction, the cells have significantly higher settlements than is normally observed in conventional cells; this means additional airspace within the same permitted boundary.

All these findings will help reduce GHGs and positively impact sustainability.

[13] This program is called Project XL by US EPA. Project XL (eXellence and leadership) is a national initiative that tests innovative ways of achieving better and more cost-effective public health and environmental protection. The lessons learnt from Project XL are being used to assist USEPA in redesigning its current regulatory and policy setting approaches.

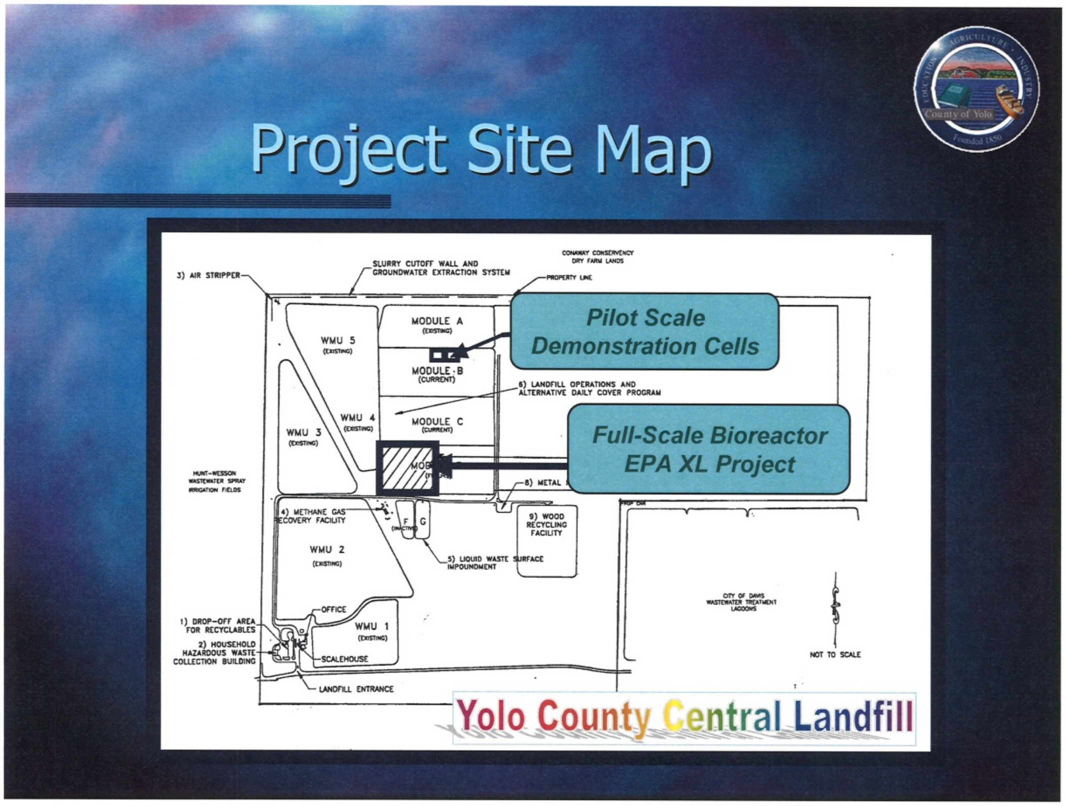

Figure 11 Yolo County Bioreactor site Plan View (Yazdani, et al, 2006)

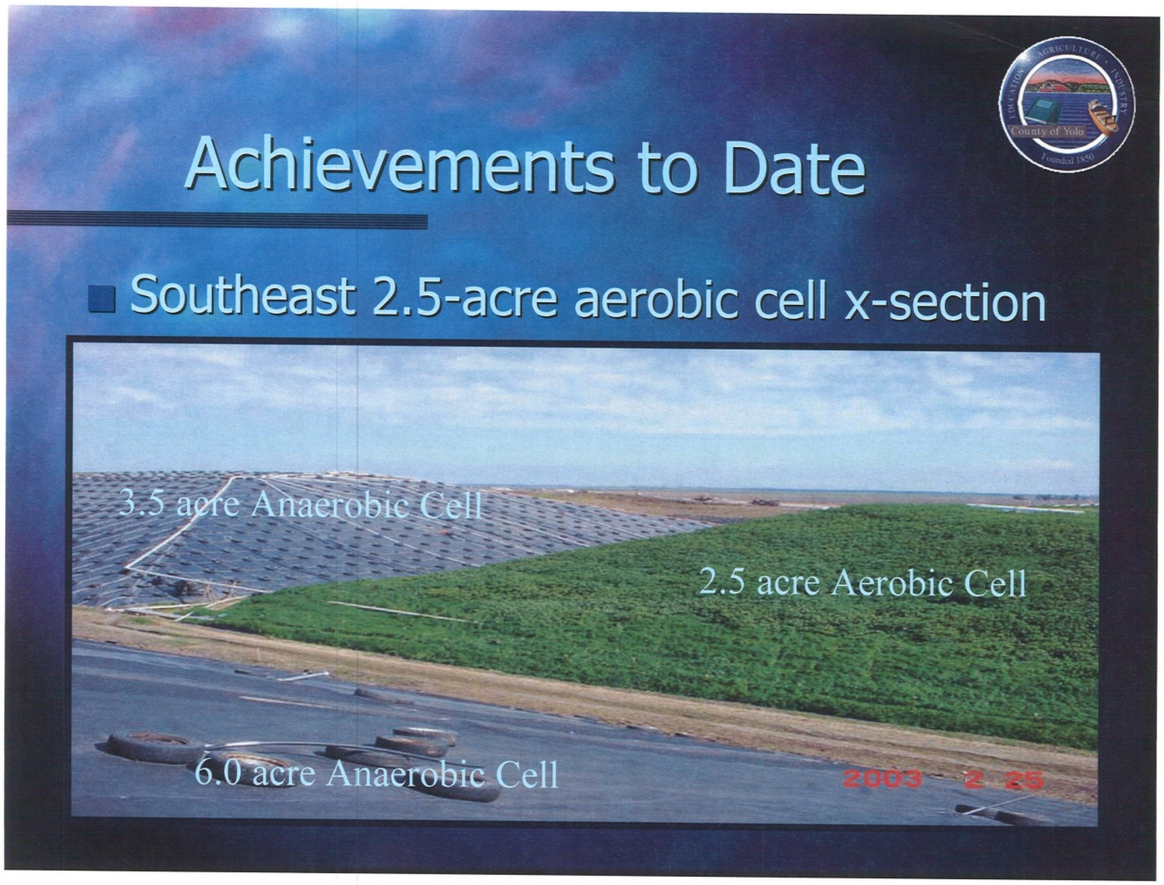

Figure 12 A Photo of the Completed Bioreactor Cells (Yazdani, et al, 2006)

WASTE PREVIOUSLY DISPOSED AND THE SITE CLOSED

Brownfield developments of parks, golf courses and light structures over closed municipal solid waste (MSW) landfills have a long history. However, construction of industrial and commercial buildings on top of MSW landfills is a relatively recent development. Additionally, green energy developments, such as, wind turbines and solar panels on top of MSW landfills are even more recent developments. Factors that need to be considered for constructions on closed landfills are: (i) large total and differential settlements, (ii) impact of construction on waste containment efficiency, (iii) impact of landfill environment on embedded facility components, such as , foundations and utility pipes, and (iv) long-term operations and maintenance issues including landfill gas control and possible contaminant migration into groundwater (Sharma, et al. 2003, Keech 1995, Sharma and Reddy 2004 and Satyamurthy, et al, 2008). These factors should be considered when designing foundations for structures founded on MSW waste landfills.

Buildings over Closed MSW Landfills

The most important issues that need to be considered for building foundation design on MSW are: (i) waste settlements, (ii) resulting down drag on the pile shaft, (iii) foundation load bearing capacity, and (iv) lateral load resistance capacity of the pile-waste system. To address these issues site specific field monitoring and load testing are generally carried out. The author was involved at two such buildings sites. The first site consisted of a commercial building, constructed over 15 years ago and the second consisted of an industrial building, built about 10 years ago. The buildings at both these sites consisted of a combination of shallow and deep foundation foundations. Site inspections indicate that the structures, at both these sites, are performing well.

Waste Settlements: For a specific load on a foundation, the settlement of the foundation depends on the underlying material thickness and compressibility properties. Settlement estimation methods for the underlying conventional soils are well documented in the literature. Settlement estimation methodology for underlying MSW landfill material is relatively new; current state of the practice is briefly presented herein.

The compressibility and hence the settlement behavior of MSW landfills is complex and depends on many factors, such as, availability of water, organic content, etc. For all practical purposes the vertical load influenced deformation, called primary settlement, is completed approximately within first four months of loading. For MSW, Sowers 1973 classified the initial settlements as primary and the long-term settlements as secondary compression. For long-term settlement estimates, it is generally agreed that MSW exhibits characteristics similar to those of organic soils (Sharma and Lewis, 1994 and Sharma and De, 2007, and Sharma, et al, 2012). The secondary long-term settlement H_s at time t_2 can be estimated by the following equation:

$$H_s = C_\alpha H \log (t_2/ t_1) \qquad (1)$$

Where, H is the thickness of refuse, t_1 is the initial period (typically 4 months) of settlement and C_α is the coefficient of secondary compression of MSW. For settlement due to external weight C_α ranges between 0.01 and 0.07 and for settlement due to self-weight C_α ranges between 0.1 and 0.34 (Sharma 2000 and Sharma and De, 2007).

The following presents two case histories, one a commercial building and the second an industrial building, both constructed on top of MSW landfill sites.

A Commercial Building Constructed on Top of a Closed MSW Landfill

This case study is for a retail commercial building built on top of a MSW landfill and is located in San Francisco Bay area. Starting from 1956 the waste was disposed of at this site in about 30.5 m (100 feet) deep borrow pit which was then closed in early 1980s when the maximum waste height reached to about 40 m (130 feet).

For this project, the various foundation design steps consisted of: (i) Field Investigations: to determine subsurface conditions, (ii) Site Settlement Monitoring and Future Settlement Estimates: to plan grading, access, drainage condition and maintenance planning during the design life of the facility, (iii) Vertical Downward and Upward Pile Design Load Capacity Estimates based on pile load testing[14], and (iv) Lateral Load Capacity Estimation for Pile Foundations based on lateral load testing[15].

Site Settlement Estimates

As discussed earlier, the major component of site settlements for a closed MSW landfill is due to the secondary settlements of the waste which can be estimated using equation (1). In this equation the only unknown is C_α which for this site was estimated by monitoring settlements at various monitoring point locations over a period of about 2 years. Figure 13 shows the monitored settlement-time plots at two monitoring points (points 1 and 5). Using equation (1) the estimated C_α is 0.22 for data at point 1 and 0.19 for data at point 5. An average of these values from the site was then used to prepare a site settlement contour map after a period of 20 years. This information was used for site grading, drainage plan and for operations and maintenance (O&M) planning for the site.

Based on above evaluations the main retail building and the parking structure were designed to be founded on driven piles. Site observations have indicated that since the completion of these structures in mid 1990s they have been performing well. This required the execution of appropriate operations and maintenance (O & M) in accordance with an Inspection and Maintenance (I & M) Plan. The site I & M Plan included inspection of pavement condition, hinged slabs, utility connections and vaults, storm water and sewer lines checked via television cameras to check their sagging and other obstructions and landfill gas monitoring and operations system check. The thickness of MSW at this site is about 100 feet. The waste is moist and above ground water levels. Therefore there is a good possibility of the existence of large amount of gas at this site. Furthermore, since this building is a closed structure the existence

[14] Vertical pullout load test was conducted with a steel pile driven into the waste. Test result interpretation indicated an interface friction angle of approximately 20 degrees; this reasonable considering MSW frictional strength parameter of 33 degrees Kavazanjian (1995), and Zekkos (2005).

[15] Lateral pile load test on a concrete pile installed through the waste indicated n_h value of 36 pound/cubic inch (9800 kN/cubic meter) which is consistent with a friction value of 33 degrees for waste; similar to loose to medium dense sand. Here k_h=n_h (x)

of gas becomes even more significant. Therefore, an active gas collection and extraction system was installed for this structure. The Figure 14 shows how the area looked in 1946 and Figure 15 shows that by 1968 the area had a landfill completed on the east side of the freeway. In a photograph of 2002 the area had commercial development (Figure 16). A Home Depot sotore was constructed over the previously landfill site (Figure 17). Figure 18 shows a view of the complete building with a gas flare system on the left; such a system or a variation of that with some form of LFG venting and monitoring is generally required when a building is constructed over a MSW landfill. This shows how a marginal or waste land can be usefully developed and thus is an example of a sustainable development.

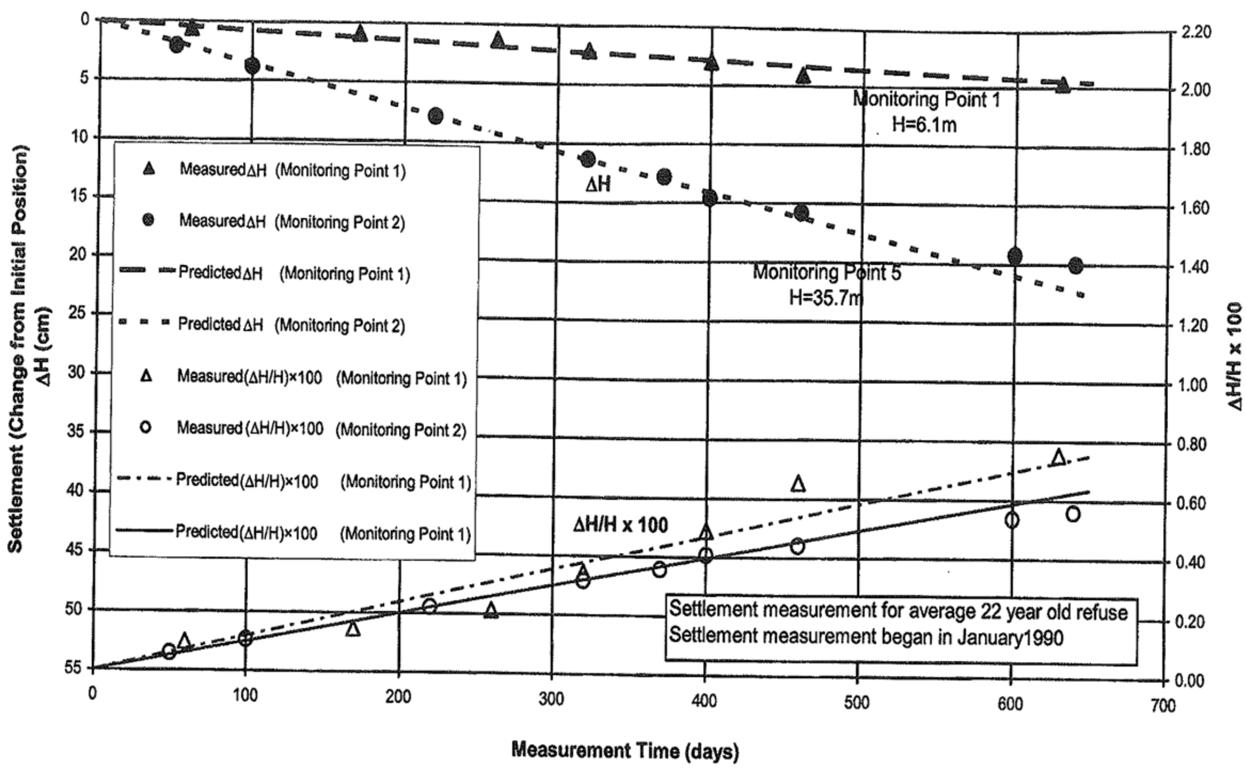

Figure 13 Load Settlement Behavior of MSW Caused by Self-weight (Sharma and De, 2007)

Figure 14 A Photo of the Area in 1946 (Sharma, 2012)

Figure 15 The Landfill in the Area in 1968 (Sharma, 2012)

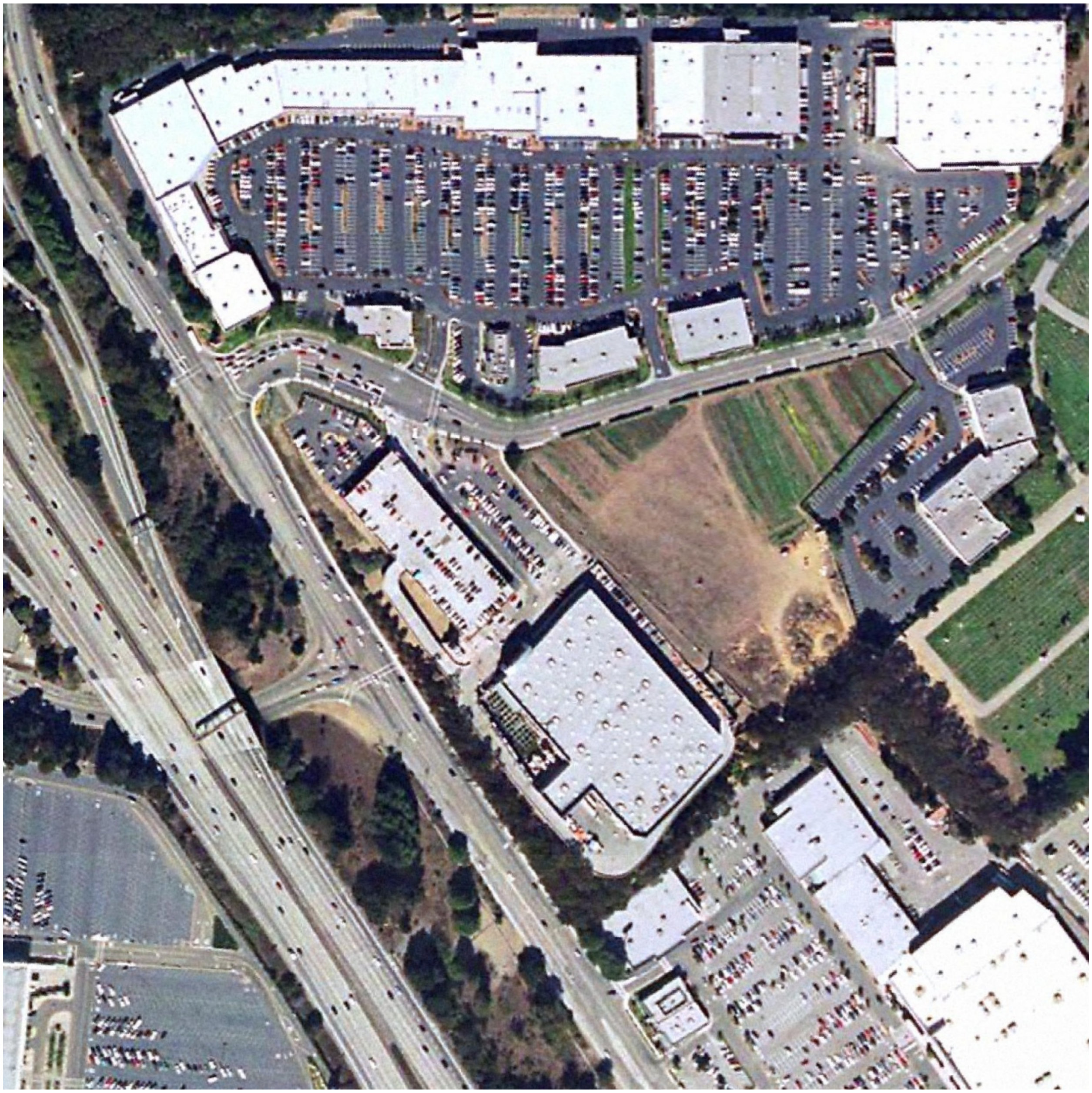

Figure 16 Commercial Developments in the Area Surrounding the Landfill (Sharma, 2012)

Figure 17 shows a photo of the completed building.

Figure 18 A View of the Completed Commercial Building with Gas Flare System Shown on the Left (Sharma, 2012)

An Industrial Building Constructed on a Closed MSW Landfill

This case study is for a Materials Recovery Facility (MRF) located in San Leandro, California constructed over a closed MSW landfill which was operational during 1940s until 1979. Waste continued to be placed as late as 1976 and the landfill was closed in 1979 by covering it with a layer of soil. A portion of the landfill was dedicated to open space/park land; a smaller portion was used to construct a transfer station and recycling complex; the MRF is a part of this complex.

As designed and constructed, the MRF building is a prefabricated steel structure measuring approximately 36.7 m (120 feet) by 91.4 m (300 feet) and housing conveyors, screens, sorting stations, and a heavy crane. Based on feasibility study it was concluded that a foundation system consisting of driven piles to support the building columns and the crane, and an independent floating slab on grade to support the other loads be selected. The columns rest on piles and the pile caps are tied with grade beams. The grade beams and the pile caps move independently of the slab on grade. The building has been functioning well for the past over 10 years. Figure 19 shows a photograph of the inside of the completed building.

Figure 19 shows a photo of the Inside of the Completed building (Sharma, 2012)

Solar Energy Generation On Top Of Closed Landfills

General Considerations

It is estimated that in the United States alone there exist over about hundreds of thousands of acres of brownfields real property; this estimate is based on about 100, 000 closed landfill sites. As the demand for new land increases there is a pressure to develop these real estate properties. In addition to their use for building development (both industrial and commercial), as discussed earlier, the use of these closed landfill sites becomes more attractive for clean energy like solar installations because such development may less likely cause community concerns in addition to their lower land costs in comparisons to greenfield development. There are, however, a few engineering challenges that installation of solar energy system faces when placed on waste management facilities, such as, landfills. These include: (i) differential settlements and possibility of localized settlement, (ii) cover material integrity, and (ii) side slopes portion of the landfills where installations of solar panels may not be most effective. This means facilities that are sensitive to differential settlements, need a large flat land area and may need to support heavy structural loads may require special design considerations.

Solar Power Technology

Solar power, converting sunlight into electricity, is available in two types of technologies: (i) Concentrated Solar Power (CSP), and (ii) Photovoltaic (PV).

(i) Concentrated Solar Power (CSP) system

CSP systems use mirrors and lenses to concentrate and collect solar energy in the form of heat which is typically used to heat water for steam powered turbines for electricity generation. CSP systems typically require cheap land, abundant cheap source of water and plenty of sun to produce thermal energy which then is used to produce electricity. Typically, such plants are large in size (hundreds of megawatts level energy production), and are typically linked to a transmission network system. Because of their need for a large flat land, and more sensitive foundation requirements, CSP systems are not suitable at landfill sites.

(ii) Photovoltaic (PV) Cell System

PV systems consist of multiple cells that consist of semiconductors made of materials consisting of monocrystalline, polycrystalline or amorphous thin films. PV systems convert sunlight directly into Direct Current (DC)[16]) electric energy by using photoelectric effect. Photoelectric effect is the excitement or movement of electrons caused by interaction between semiconductor material and the energy from the sun. Although monocrystalline panels provide most efficient power generation per unit area but they generally are costly and heavy. Additionally, both the monocrystalline, and polycrystalline are rigid (flat panel) which would require mounting on a rigid frame. On the other hand amorphous cells have lower efficiency than the other two but are of lighter weight and due to their flexibility are mounted on flexible surfaces or panels. Flat panels can either be mounted on a fixed system as a rigid foundation or have a tracking mechanism to follow the sun throughout the day.

Power generation efficiency of a PV system depends on various factors, such as, tilt or the type of sun tracking PV system, panel orientation, and overall AC-DC inverter efficiency. However, solar power radiation (i.e., latitude and longitude location of the site) is an important factor in making a decision on installing solar power system at a site. For the United States, a map such as shown in Figure 20 can be used in estimating the solar energy that can be produced at a specific location in the US, in $kWh/m^2/day$.

[16] The direct current (DC) can be converted to the alternating current (AC) by using inverters

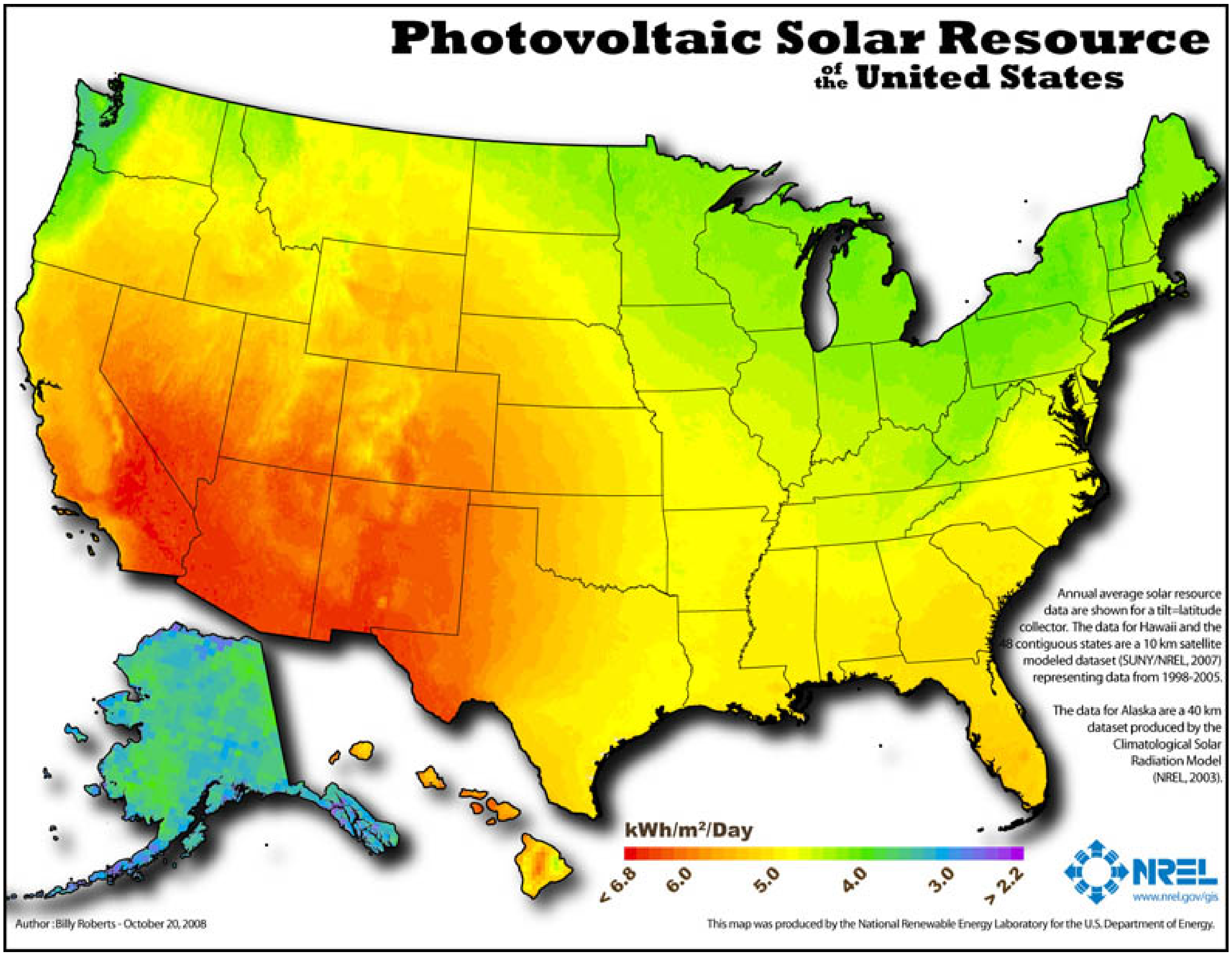

Figure 20 Photovoltaic Solar Resource Map of the United States (National Renewable Energy laboratory Solar Map by Roberts, 2012)

As discussed above, for closed landfill applications, amorphous thin films PV systems are the most applicable system. However, other systems have also been used on the landfill sites. These systems can either be used for small scale power applications or can be connected to an electricity grid. A review of the summary on Watts per pound of various cells types by various manufacturing brands indicates that polycrystalline cells may have about 4 to 6 Watts/ Pound, monocrystalline may have about 3 to 4 Watts/Pound and amorphous thin films may have about 2 to 8 Watts/Pound of energy production (Sampson, 2009).

Solar Power Case History Projects

There are a number of case histories where PV systems have been installed on closed landfills in the US. A few examples are: (1) Nellis Air Force Base Site: A 14.2 megawatts capacity solar energy system has been constructed on a 140 acre site at the Nellis Air Force Base, NV, at a closed MSW landfill site. The system consists of single axis sun-tracking units manufactured by SunPower; the system consists of 5,821 sun-tracking mounting systems placed on concrete foundations. (2) Tessman Road Landfill Site: In 2009, a Solar Energy Cover (SEC) system was constructed at Tessman Road Landfill, San Antonio, Texas[17]. The SEC system covers about 6-acre site where the geomembrane cover system known as SEC functions both as landfill cap and mounting surface for flexible PV

[17] Coupled with the gas technology the site produces 9 megawatts of electricity

panels. (3) Pennsauken MSW landfill Site: A 2.1 megawatts capacity solar system at the Pennsauken MSW landfill site in NJ was constructed using PV panels on cell's side slopes and the top deck. The mounting consisted of concrete ballasted on top deck and pre-cast concrete footings on the side slope. (4) Hickory Ridge Landfill Site: Figure 21 shows the Hickory Ridge Landfill, GA after the full waste fill capacity was achieved with cover soil. Figure 22 shows a photo of the Hickory Ridge landfill which, in 2011, was closed with a dual purpose landfill closure system: an exposed geomembrane solar cover (EGSC). It has ground mounted flexible PV with power generation capacity of 1.0 megawatt installed on the southwest and southeast landfill slopes and consists of about 7,000 flexible solar laminates manufactured by UNI-SOLAR. It consisted of 60-mil scrim reinforced thermoplastic polyolefin (TPO) geomembrane cover over a 48-acres area. During construction, the photovoltaic/ geomembrane rolls were unrolled and heat bonded to like panels of TPO geomembrane. The system electricity is being directly sold to Georgia Power.

This 48-acre landfill solar energy project has transformed a closed landfill not only to produce clean energy but also has helped "avoid thousands of tons of greenhouse gases that would have emitted from mowing and soil replacement activities for long term maintenance." Also, the clean surface run off water can be used without treatment rather than needing cleanup for sediments. This example, along with others, exhibits that the closed landfill sites can be successfully used for green energy projects. These can, thus, help us achieve a sustainable environment without slowing down the development – a sensible win-win scenario.

Figure 21 Hickory Ridge Landfill Prior to Installation of Solar Panels[18]

[18] Wikipedia: Photo taken on 8/25/2010: CarlisleEnergy.

Figure 22 Solar Panels on Top of a Closed Landfill: Hickory Ridge Landfill [19]

[19] Wikipedia: photo taken on 6/21/2011.

CONCLUSIONS AND RECOMMENDATIONS

Based on the information and case histories presented above, the following conclusions and recommendations are made:

1. Although sustainability has been understood differently by the professionals, one common understanding is that, "it is the condition of maintaining a process or state at a certain level for perpetuity." In waste management and geoenvironmental engineering terms: sustainability is making marginal and waste lands and waste products into usable properties, products and services.
2. An integrated flow diagram has been forwarded to explain as to how previously generated waste and currently generated wastes can be dealt with so that sustainable development can be pursued.
3. Existing waste disposal sites can be made environmentally efficient by maximizing the available airspace by utilizing technologies, such as, MSE berm and bioreactors.
4. Closed disposal sites can be recovered by developing them as parks, golf courses, industrial and commercial buildings and renewable energy production projects, such as solar energy projects.
5. It is recommended that incentives be provided to industry so that technologies, such as, bioreactor, gas to energy, and renewable energy technology (solar and wind) projects become cost effective at marginal land sites, such as, waste disposal sites.
6. It is also recommended that more pilot scale projects, on available technologies, be encouraged so that those categorized here as incubators today become reality tomorrow. A couple of examples for such developmental projects are: plasma arc, Agilyx technologies, and energy parks.

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