

Technical Assistance:

Solar Power Analysis and Design Specifications



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Through the Environmental Protection Agency's
Brownfields Program

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1 INTRODUCTION

Under the U.S. Environmental Protection Agency's (EPA) Brownfields Program, the City of Houston was selected as a Brownfields Sustainability Pilot Community. In support of this pilot, SRA International (SRA) was tasked to provide assistance to the City of Houston to provide technical and economic analyses on a proposed solar power farm on a former landfill. This work was performed under EPA Contract No. EP-W-07-023, Work Assignment 018, entitled, "Technical Assistance to Pilot Communities."

1.1 EPA Brownfields Program

EPA's Brownfields Program empowers states, communities, and other stakeholders to work together to prevent, assess, safely clean up, and sustainably reuse brownfields. A brownfield site is real property, the expansion, redevelopment, or reuse of which may be complicated by the presence or the potential presence of a hazardous substance, pollutant, or contaminant. EPA's Brownfields Sustainability Pilots provide technical assistance to support communities in achieving greener, more sustainable assessment, cleanup, and redevelopment at their brownfields projects. These pilots will also serve as models for other communities across the country.

1.2 City of Houston Project Description

The City of Houston, Texas anticipates that the revitalization of the 300-acre Holmes Road Landfill site located 10 minutes from downtown Houston will create positive environmental impacts such as a healthier ecosystem, increased safety for surrounding residents, economic development, and historical restoration. EPA assistance, provided through SRA, will help the city analyze the environmental and engineering issues of building a solar plant on a former landfill. SRA will also help conduct solar energy production and financial feasibility studies. The redevelopment of the city-owned landfill site into a solar farm will help spur a viable local market for solar energy systems and lead to the creation of the jobs.

1.3 Technical Assistance Overview

The technical assistance provided to the City of Houston was designed to provide analysis support in the areas of environmental review, preliminary engineering design, solar photovoltaic (PV) system conceptual design and specifications, solar farm turn-key costs, solar system output, and economic valuation. In completing these tasks, the goal was to provide the city with current and accurate information on the costs and benefits, and regulatory requirements for building a solar farm on a former landfill owned by the city. Specifically, the analyses completed under this study were performed through the following seven tasks:

- Task 1: Conduct on-site photovoltaic project assessment
- Task 2: Regulatory assessment
- Task 3: Site engineering assessment
- Task 4: Determine PV system size, conceptual design elements, and specifications
- Task 5: Develop installed cost estimates for the solar farm
- Task 6: Conduct economic analysis of the proposed solar farm's characteristics
- Task 7: Develop a final report

These tasks were completed by SRA with assistance from City of Houston personnel, EPA staff, and subcontractor, Tetra Tech, Inc. All information and analyses provided in this report are based upon data provided by project participants, industry standard costs and modeling procedures, and current regulatory requirements. The information and results presented in this report may be subject to change based on changes in market conditions, regulatory or legislative initiatives, and/or technology advances.

The following sections detail the scope of work elements completed in support of this project, as well as provide recommendations for next steps towards solar project development and power purchase agreement negotiation and finalization.

2 TASK 1: CONDUCT ON-SITE PHOTOVOLTAIC PROJECT ASSESSMENT

SRA personnel travelled to Houston on August 18 and 19, 2008 to kick off the solar analysis project through meetings with City of Houston staff and a site visit to the Holmes Road landfill. A detailed site visit report was submitted on October 16, 2008; this report is briefly summarized below.

2.1 Site Visit Summary

SRA and City of Houston staff conducted a site visit of the Holmes Road Landfill on August 19, 2008. The site was visible on three sides from the road, but was not accessible via auto, and only small portions were accessible by foot. The site was capped in the mid 1970s and is heavily overgrown with large trees and brush (see photos 1 and 2 below).



Photo 1. Holmes Road Landfill from Sunnyside Park



Photo 2. Holmes Rd. Landfill–Abandoned Road (Incinerator Dr.) Cutting through Middle of Parcel

Due to the severe overgrowth at the landfill site, SRA and City of Houston staff were unable to physically walk the site. However, several observations were able to be made by driving around the site on the sides accessible by road. The site is bordered on the north by Bellfort Street, on the west by Comal Street, on the south by Reed Road, and on the east by Highway 288. There is a police station and library near the corner of Comal Street and Reed Road, and Sunnyside Park is on the corner of Comal Street and Bellfort Avenue.

While utility distribution lines are adjacent to the landfill site on three sides, the north and west sides of the landfill had significantly smaller distribution lines which were estimated to have a lower carrying capacity than the larger line on the south side of the landfill running along Reed Road. Further investigations will be necessary to determine both the load carrying capacity of the line on the southern side of the parcel, as well as the available capacity on the line. This information is necessary to determine how much capacity can be added to the distribution line from a proposed solar power farm, and if the line will need to be upgraded to accept planned and potential future levels of power from the site.

The site will need to be cleared and graded. Clearing and grading of the site will require consideration to not disturb the landfill cap, and avoid any potential areas with lead contamination. Based on the Terracon Environmental Site Investigation Report, there is only one known area contaminated by lead. Initial estimates obtained by the city indicate a cost of \$7,000 per acre to clear the landfill area to be designated for solar farm development.

Based on the site visit, SRA has determined that the land best suited for solar farm development roughly comprises the southern half of the Holmes Road Landfill. This is due to a number of reasons, including:

- The higher capacity distribution line parallels Reed Road on the southern edge of the property; thus the interconnection site to the utility grid would be at the southern edge of the property.
- Since the solar panels need to be facing south, siting them adjacent to Reed Road on the southern edge of the property will eliminate any potential solar obstructions, as well as eliminate the need to clear additional land as a buffer zone to clear solar obstructions. Alternatively, if the solar farm were sited on the northern portion of the landfill, a buffer zone would need to be cleared south of the solar farm to eliminate obstructions from the tall trees and overgrowth existing at the site. Reducing the amount of land that needs to be cleared and graded will also reduce overall project costs.
- Siting the solar farm on the southern half of the landfill also provides increased visibility of the solar panels to the public, thereby providing increased public relations benefits. Vehicle traffic on Reed Road will see the front of the panels, which are much more aesthetically-pleasing than the back of the panels. Conversely, siting the farm on the northern half of the landfill would allow drivers on Bellfort Street to only see the back side of the panels. Perhaps more importantly, siting the project on the southern half of the landfill and along the edge of the eastern boundary of the site will make the solar farm highly visible to traffic along Highway 288, an elevated and heavily travelled route.
- While the solar farm will be required to have a security fence, solar panels are prone to theft, particularly during periods of increasing electricity costs. Siting the solar farm on the southern half of the landfill will place it adjacent to the local police station, and provide an enhanced level of security and safety.
- Siting the solar farm on the southern half of the landfill will not disturb the “urban forest”-type boundary around Sunnyside Park. The edge of the landfill property surrounds the park and provides a natural boundary of trees and overgrowth which acts as both an aesthetic backdrop and a noise barrier from Highway 288.

Even though the landfill area was inaccessible by foot, the site visit was an extremely beneficial exercise in terms of determining probable electrical interconnection points, the “best fit” siting of the solar farm based on the property and surrounding area’s characteristics, and the preliminary engineering requirements and design characteristics necessary for the project.

2.2 10 MW Solar Farm Footprint and Preliminary Recommendations for Site Preparation

Based upon a review of existing data and research reports, the site visit, and on-site discussions with City of Houston staff, a number of initial conclusions and recommendations can be made as part of the site visit analysis. First, it is recommended that the solar farm be sited on the southern portion of the Holmes Street Landfill. Second, based on discussions with city management, and their interest in developing the site with amorphous silicon (A-si) solar panels from an Applied Materials (AMAT) or equivalent manufacturing line, it was possible to develop an approximate footprint of the proposed 10 MW solar farm. Currently, amorphous silicon solar panels produced from the current generation of the Applied Materials manufacturing line have conversion efficiencies in the 6-7.5 percent range. These modules are large, utility scale panels with dimensions of 2.2 x 2.6 meters, and would be mounted with a fixed tilt of 30 degrees if designed to maximize for annual energy production. Based on these assumed efficiencies and mounting structures, 1 MW of solar PV would require approximately 15 acres of land to account for adequate spacing between rows to avoid row-on-row shading, as well as account for inverter pads and

other balance of system components. 15 acres per MW is an approximate estimate based on currently available and known information, with the final dimensions to be determined in the design-build process. Thus, a 10 MW solar farm at the landfill would require approximately 150 acres, or half of the land available at the site. Figure 1 on the next page provides the recommended footprint for the 10 MW solar farm. This is a preliminary recommendation, and final dimensions should be determined during the design-build process to account for exact module efficiencies, row spacing, and site preparation considerations.

With respect to site preparation, it will be necessary to clear and grade the site. Clearing the site of trees and brush must be done in a manner that does not significantly disturb the landfill cap, particularly in areas with minimal soil cover over the landfill waste. Most importantly, the landfill cap should not be penetrated to expose the waste material. This may require, for example, that tree roots extending into the subsurface landfill waste be left in place and covered. Once the site is cleared of the wood, brush, and other associated waste materials, the site will require grading to provide a level surface for the construction of the solar farm. The grading requirements will be determined in the final design during the design-build process. However, since the mounting structures will likely require about three feet of depth for the pouring of the footings and installation of the racks supported by the footings, at least four feet of soil cover will be required on the approximately 150 acre site. The exact depth of the cap cover will be determined in the design process as a function of the dead weight loading of the system on the footings. To obtain the required depth of the cap, it will require the movement of soil from higher depth landfill cap areas to areas of the cap which are currently shallow (i.e., less than four feet), and may possibly require additional top soil to be brought to the site to provide adequate cap cover for the footings. In addition, grading the site to a zero degree slope is not required, as a slope rising from the south to north is acceptable. Once the site is cleared and graded, a permanent security fence will be required to be erected to protect against theft, vandalism, as well as for public safety.

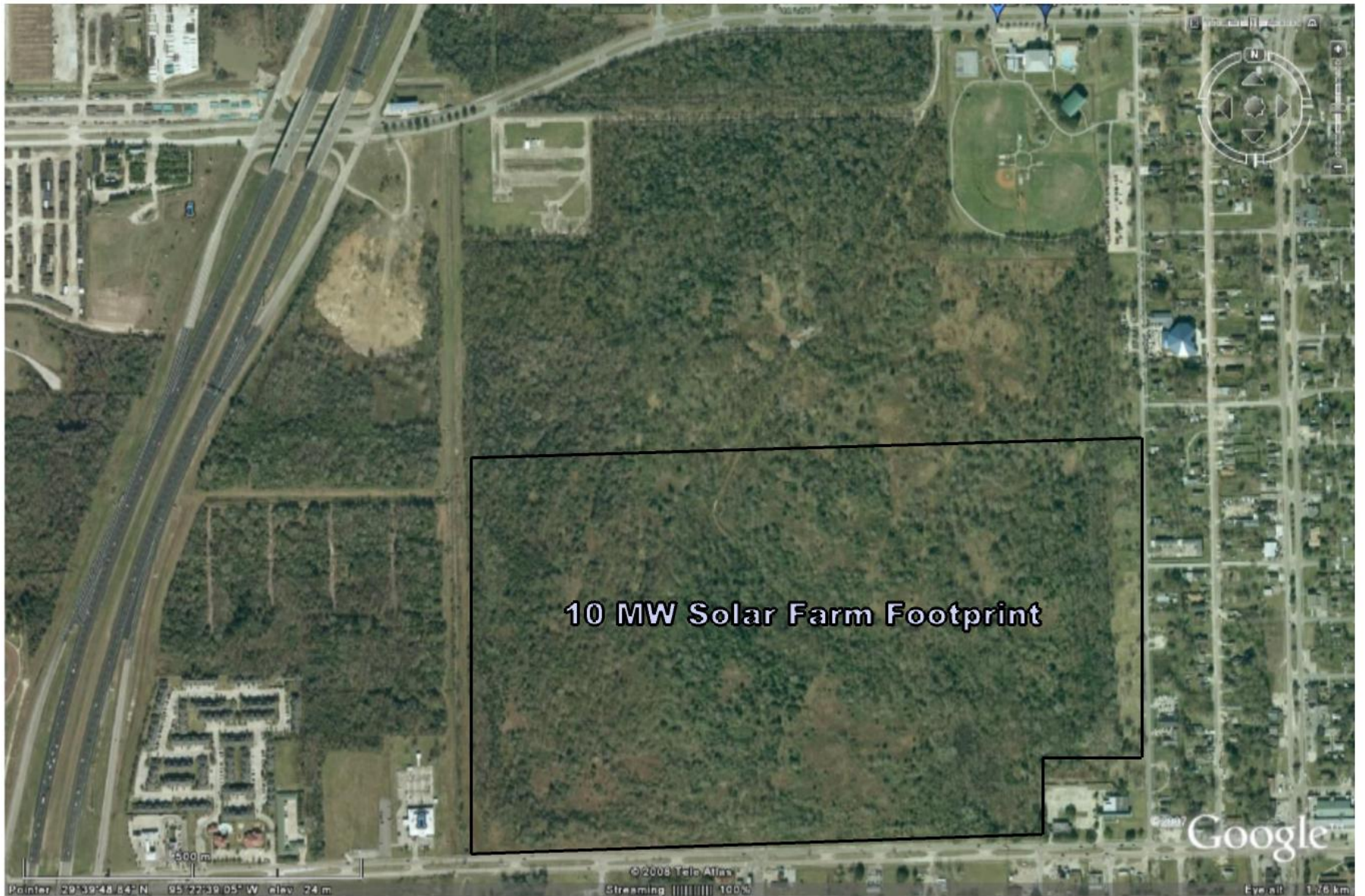


Figure 1. Approximate Footprint of Proposed Solar Farm

3 TASK 2: REGULATORY ASSESSMENT

SRA tasked its team subcontractor, Tetra Tech, Inc. (Tetra Tech) to provide regulatory support concerning Resource Conservation and Recovery Act (RCRA), state, and local solid waste requirements and approvals needed for the project. The proposed property for the solar plant is an approximately 300-acre parcel known as the former Holmes Road Landfill, (Holmes Road) located between Bellfort Street and Reed Road, east of Highway 288 and west of Comal Street, approximately 10 minutes from downtown Houston, Harris County, Texas.

RCRA Subtitle D addresses non-hazardous solid wastes, including municipal solid waste. Under Subtitle D, the state and local governments are the primary planning, permitting, regulating, implementing, and enforcement agencies for management and disposal of household and industrial or commercial non-hazardous solid wastes.

At a local level, the Houston-Galveston Area Council (H-GAC) is the state designated planning agency for solid waste management issues in the region. The H-GAC Solid Waste Program reviews applications for landfill permits and solid waste grants. H-GAC provides technical assistance to local governments on solid waste issues, and provides continuing education opportunities for local governments and solid waste professionals. In 1993, the Texas Legislature passed House Bill (HB) 2537, which required Councils of Governments (COGs) to develop an inventory of closed municipal solid waste landfills for their regional solid waste management plans. The bill was in response to concerns and incidents involving public health and safety when development occurred over property once used for waste disposal. More information concerning the H-GAC can be found online at: <http://www.h-gac.com/community/waste/default.aspx>.

According to H-GAC's Closed Landfill Inventory, exact dates of operation are not available for the Holmes Road Landfill, but it was reportedly used for disposal of brush, construction and demolition debris, household waste, industrial waste, tires, and scrap. The H-GAC inventory also stated "closure indicated in 9/16/70 Houston Chronicle article," which implies that the landfill was closed in 1970.

At a state level, the Texas Commission on Environmental Quality's (TCEQ) Municipal Solid Waste program is the regulating agency, and TCEQ's "facilities, applications, and correspondence" online database indicates that the Holmes Road Landfill has been closed since the mid-1970s.

The City of Houston is the current owner of the property, and has conducted various environmental site investigations of the Holmes Road Landfill, including a recent study (September 2006), when Terracon, on behalf of the city, conducted a limited Environmental Site Investigation (ESI) of the landfill.

Based on information in the H-GAC and TCEQ databases, and the September 2006 ESI, the Holmes Road Landfill appears to be a closed landfill that was developed before permitting requirements were put in place.

Use of land over closed municipal solid waste landfills in Texas (including permitted municipal solid waste landfills that are no longer in post-closure care, closed landfills that were developed before permitting requirements, and closed unauthorized landfills) is regulated under the rules for persons owning, leasing, or developing property or structures overlying a closed municipal solid waste landfill, in [30 Texas Administrative Code \(TAC\) Chapter 330, Subchapter T](#). The rules include the following:

- §330.951 – Definitions
- §330.952 – Applicability and Exemptions
- §330.953 – Soil Test Required Before Development
- §330.954 – Development Permit, Development Authorization, and Registration Requirements, Procedures, and Processing
- §330.955 – Miscellaneous
- §330.956 – Application for Proposed or Existing Constructions Over a Closed Municipal Solid Waste Landfill Unit, General Requirements
- §330.957 – Contents of the Development Permit and Work Plan Application
- §330.958 – Construction Plans and Specifications
- §330.959 – Contents of Registration Application for an Existing Structure Built Over a Closed Municipal Solid Waste Landfill Unit
- §330.960 – Contents of Authorization Request to Disturb Final Cover Over a Closed Municipal Solid Waste Landfill for Non-enclosed Structures
- §330.961 – Operational Requirements for an Enclosed Structure Over a Closed Municipal Solid Waste Landfill Unit or a Municipal Solid Waste Landfill in Post-Closure Care
- §330.962 – Notice to Real Property Records
- §330.963 – Notice to Buyers, Lessees, and Occupants
- §330.964 – Lease Restrictions

It is important to note that many of the requirements found in these rules are applicable to development of “**enclosed structures**” on closed landfills. “**Enclosed structures**” are defined in §330.951 as:

“Any permanent structure that is intended to be or has the potential of being used or occupied by people for an industrial, commercial, public, or residential purpose.”

A solar power plant would not meet the definition of an “enclosed structure,” therefore many of the TAC Chapter 330, Subchapter T requirements are not applicable to the Holmes Road Landfill project. The rest of this regulatory summary outlines requirements applicable to the development of a solar power plant as a **non-enclosed structure** on the Holmes Road Landfill.

Rule §330.953 requires soil testing prior to or during development and construction of structures on a closed municipal solid waste landfill, and it would appear that the September 2006 Terracon limited Environmental Site investigation meets the requirements for soil testing prior to development. The City of Houston should ensure that all notifications required by §330.953(d) have been properly made.

While Rule §330.954(a) through (d) apply to development permits for development of enclosed structures and are therefore not applicable to the solar power plant, **the authorization request requirements for non-enclosed structures outlined in §330.954 (e) may apply, if the final cover is to be disturbed in any way.** It states the following (emphasis added):

“(e) Authorization to disturb final cover for non-enclosed structures.

(1) The integrity of the final cover of a closed MSW landfill shall not knowingly be violated, disturbed, altered, removed, or interrupted in any way without the prior authorization of

the executive director, except where soil tests are being performed in accordance with §330.953 of this title.

(2) Penetrations of the final cover or liner systems will not be allowed without the prior authorization of the executive director. These include, but are not limited to, borings, piers, spread footings, foundations for light standards, fence posts, anchors, deadman anchors, manholes, on-site disposal systems, recreational facilities, and any other kind of non-enclosed structures.

(3) An authorization to disturb final cover issued by the executive director under this subchapter is not an authorization for the management of solid waste. An application for authorization shall comply with those requirements in this subchapter.

(4) The authorization request must be received at least 45 days prior to the proposed commencement of construction over the closed MSW landfill unit.”

Rule §330.960 outlines the contents of an authorization request to disturb the final cover over a closed municipal solid waste landfill for non-enclosed structures:

“The owner of a property that includes a closed municipal solid waste landfill shall not disturb the final cover without prior written approval from the executive director. The authorization request shall include the following:

(1) a certification as set forth in §330.957(b) of this title (relating to Contents of the Development Permit and Workplan Application);

(2) the existing conditions summary as set forth in §330.957(c) of this title;

(3) proposed project description including location related to the closed landfill;

(4) description of the construction/investigation process including, but not limited to, work schedule and safety issues during construction;

(5) description of the procedures for water and/or methane monitoring and excavated material disposal during construction;

(6) maps and drawings, site drawing, and general location map to indicate the landfill location; and

(7) engineering plans, sealed and signed by a licensed professional engineer indicating the proposed project description and its location relative to the landfill.”

As noted above, the authorization request must comply with §330.957(b), and contain a certification statement that follows the specific language of the regulations (see text below):

(b) Certification.

(1) Following the language of Texas Health and Safety Code, §361.533, the licensed professional engineer preparing a development permit application shall include the following certification: Certification of No Potential Threat to Public Health or the Environment. "I,

_____, P.E. # _____, certify that the proposed development is necessary to reduce a potential threat to public health or the environment, or that the proposed development will not increase or create a potential threat to public health or the environment. Further, I certify that the proposed development will/will not damage the integrity or function of any component of the Closed Municipal Solid Waste Landfill Unit, including, but not limited to, the final cover, containment systems, monitoring system, or liners. This certification includes all documentation of all studies and data on which I relied in making these determinations." (signed, sealed, and dated by the licensed professional engineer)."

Also as noted above, §330.960 states that the authorization request must include an existing conditions summary, as outlined in §330.957(c):

“(c) Existing conditions summary. The owner shall discuss any land use, environmental, or special issues that affect the facility. This shall include, but not be limited to:

- (1) condition of final cover;*
- (2) waste characterization;*
- (3) gas production; and*
- (4) potential environmental impacts.”*

It would appear that other than §330.957(b) and (c), none of the other information requirements in §330.957 are required for a non-enclosed structure (where the final cover will be disturbed in some way) authorization request.

Rule §330.955 contains miscellaneous requirements for developing property or structures over a closed municipal solid waste landfill. It should be noted that some of the requirements in this rule could be applicable to the solar power plant project; however, a determination on the applicability will need to be made as the project develops:

“(b) The executive director may require that additional soil layers or building pads be placed on the final cover prior to the initiation of any construction activity or structural improvements in order to protect the integrity and function of the final cover, any liner(s), any components of the containment system(s), or any monitoring system(s).

(c) The executive director may allow small amounts of solid waste removed from a closed MSW landfill (including residuals from a soil test) to be redeposited in the closed MSW landfill on a case-by-case basis. The workplan for developing land over a closed MSW landfill should describe the steps taken to ensure that removed waste will be appropriately covered or removed to an authorized waste management facility.

(d) Unauthorized pilings in or through the final cover of a closed MSW landfill are prohibited.

(e) Unauthorized borings or other penetrations of the final cover of a closed MSW landfill are prohibited.

(f) Any water that comes in contact with waste becomes contaminated water and has to be properly discharged in a manner that will not cause surface water or groundwater contamination.

(g) Locations where waste is removed shall be backfilled and compacted with clean high-plasticity or low-plasticity clay. The excavation shall be backfilled to exceed the existing grade and provide positive drainage.

(h) No waste shall be left exposed overnight.”

Rule §330.956 outlines additional permit application requirements that appear to be limited to enclosed structure development permits. While Tetra Tech has not been able to confirm this assumption with TCEQ, the rule does not appear to apply to the solar power plant development.

Rule §330.962 applies to the owners of property that overlies a closed municipal solid waste landfill. If the City of Houston is the owner of the solar power plant, this rule may be applicable:

“(a) Owner of property. An owner of property that overlies a closed municipal solid waste (MSW) landfill shall prepare and file for record in the real property records in the county where the land is located a written notice stating:

(1) the former use of the land;

(2) the legal description of the tract of land that contains the closed MSW landfill, and at the owner's discretion, the portion of the tract of land that contains the closed MSW landfill;

(3) notice that restrictions on the development or lease of the land exist in Texas Health and Safety Code, Chapter 361, Subchapter R and this subchapter; and

(4) the name of the owner.

(b) Local government official. A local government official who receives notice under §330.953 of this title (relating to Soil Test Required before Development) that a closed MSW landfill exists on a tract of land shall prepare and file for record in the real property records in the county where the land is located a written notice stating:

(1) the legal description of the tract of land that contains the closed MSW landfill;

(2) the current owner of the tract;

(3) notice of the tract's former use as an MSW landfill unit; and

(4) notice that restrictions on the development or lease of the land exist in Texas Health and Safety Code, Chapter 361, Subchapter R and in this subchapter.”

Tetra Tech understands that recommendations for site preparation have not been finalized. Tetra Tech recommends that careful consideration be given to TAC Chapter 330 rules prior to finalization of site preparation plans. If the final cover of the former Holmes Road Landfill is “disturbed in any way,” (see specifically §330.954 [e] above), an authorization request will need to be prepared and submitted for TCEQ approval.

4 TASK 3: SITE ENGINEERING ASSESSMENT

The site engineering task served to identify general engineering requirements and constraints associated with the development of a large scale PV system at the former landfill site. Based on the site visit and a review of existing reports and data, there are two key constraints to consider in developing a solar farm at this site, and landfills in general. The first constraint is associated with the landfill cap and the need to avoid penetrating the soil cap into the waste area when setting the foundations for the solar racks. The second constraint is associated with differential settlement of the landfill surface due to settling of waste material below the cap. While the landfill was capped more than 30 years ago, and most of the differential settlement has likely already occurred, it should still be considered during the design process. Both of these constraints can be overcome by proper PV equipment selection and system design. All site engineering should be performed in accordance with the environmental rules and regulations specified in Section 3 of this report.

4.1 Site Preparation Engineering

The first step in preparing for the solar development at the landfill involves the preparation of the site for construction. Site preparation includes clearing the site, filling and grading, and compaction. First, all trees, brush, and overgrowth will need to be cleared without penetrating the landfill cap. Precautions should be taken such that clearing equipment, such as bulldozers, does not scrape the soil cap to the extent that waste material is exposed. This is of particular importance in areas where the soil cap is only one foot or less in depth. In addition, trees with root structures that extend into the waste material below the cap will require a mitigation strategy that avoids pulling tree trunks out that could result in exposing waste material. For example, tree trunks may need to be cut at the cap level and left in place with compacted fill placed over them.

Next the site will need to be graded and possibly filled with top soil in places to achieve a uniform cap depth at a minimum of four feet. The exact depth of the soil cap required will be determined during the design phase of the project. With some areas of the soil cap exceeding 15 feet in depth, it may be possible to move soil from these higher cap depths to lower cap depths. It is not necessary for the site to be graded to a zero slope, as a rising slope from south to north is acceptable, and would possibly allow the distance between rows of solar arrays to be smaller due to the reduction in shading distance requirements. Again, it will be important during the grading process to not penetrate the soil cap while moving and grading top soil at the site; it will also be important not to disturb any areas previously identified as having lead contamination present. After the site is graded it will likely need to be compacted to provide a solid base for the solar arrays and mitigate potential settlement at the newly filled and graded site.

4.2 Photovoltaic Equipment Selection and System Design Criteria

In general, there are two types of PV system configurations utilized in large scale solar developments, fixed tilt and single axis tracking mounting structures. Fixed tilt systems are typically rack mounted systems with the panels installed at a fixed angle, normally at or near the latitude of the site (30 degrees for the Houston site) to maximize for annual energy production (see Figure 2 below). Single axis tracking systems employ an actuator system that rotates an axis so that the panels track the sun from east to west over the course of a day (see Figure 3 below). The trade-offs between these two systems include:

- Fixed tilt systems are lighter in weight, are less expensive, and produce less energy per installed kW on an annual basis than a single axis tracking system;

- Single axis tracking systems are heavier (requiring deeper piers for footings), more expensive, and produce more energy per installed kW on an annual basis than a fixed tilt system.



Figure 2. Example of Fixed Tilt Mount



Figure 3. Example of Single Axis Tracking Mount

Since both weight and pier depth are critical design criteria for avoiding both deeper pier depths and differential settlement, a fixed tilt mounting structure is recommended for use at this site. In addition, any differential settlement that does occur would have a detrimental impact on a single axis tracking system, as

the tilt angle of the tracking system would no longer be optimized and result in reduced system output. The impacts of differential settlement on a fixed tilt system would be minimal except in cases where a high degree of settling was to occur.

The most common design for fixed tilt systems is a pier and footing configuration wherein holes are drilled in the soil, and concrete footings poured in the bottom of the hole. Piers are then attached to the concrete footings, with the racks attached to the piers. The depth of the piers is determined by the dead weight point loads supported by the piers and footings. This is a critical component of the design process, as the depth of the piers will determine the required cap thickness to contain the piers as well as support the footings. Typically the pier depth for a fixed tilt mounting system can be as shallow as three feet deep, particularly if lighter weight panels are used which require lighter weight racking systems.

An alternative design strategy to the pier and footing configuration would be to pour a concrete slab foundation corresponding to the length and width of the row of a fixed tilt array, and mount the array directly to the concrete slab. This design strategy would avoid the need for drilling holes into the cap altogether. However, this strategy would result in considerable additional cost to the project, and would also significantly increase the weight of the system resting on the landfill surface. This additional weight could cause increased differential settlement at the site, which would then crack or break the concrete foundations.

The type of PV panel selected also has an impact on the design criteria. There are two general types of PV panels with numerous variations within each type with respect to size, shape, substrate, and cell materials. These two panel types are mono/poly-silicon and thin film. Mono- or poly-silicon are higher efficiency (produce more power per unit area) panels, but typically weigh more and cost more on a dollars per watt basis. Thin films are lower in module efficiency, but cost less, and typically weigh less. Some thin film modules (such as Cadmium Telluride or Copper-Indium-Gallium-Selenide) are heavier, but the amorphous silicon thin film panels are lightweight. Since solar system weight is a critical element of the design criteria, an amorphous silicon PV panel would be preferential for this application. While amorphous silicon is lower in efficiency than a mono- or poly-crystalline panel, this is not of significant concern since these panels cost less and the availability or cost of land is not a factor for this project.

The final design criterion to be considered is wind loading. The industry standard is to design a system to withstand 120 mph winds. This is primarily addressed through specification of mounting system structure components, namely piers and racks of significant gauge steel to withstand high winds. In addition, designing the mounting structures so that the panels are mounted close to the ground can also assist in reducing potential damage from high winds. Mounting the panels close to the ground provides an additional benefit of reducing system weight and as a result reduced pier depth requirements.

Based on this general engineering assessment, it is recommended that the site be developed with fixed tilt (30 degree) mounting structures employing amorphous thin film panels. In discussions with the city, it was determined that this configuration was the preferred system type and design. Specifically, the city is exploring the use of panels from an Applied Materials or equivalent production line which produces large, amorphous silicon thin film modules. The general engineering analysis presented in this report confirms this choice of panel type, as well as the fixed tilt mounting structure. This system type and design will have the least impact on the landfill site, and require the least amount of mitigation of the site during project development.

5 TASK 4: DETERMINE PV SYSTEM SIZE, CONCEPTUAL DESIGN ELEMENTS, AND SPECIFICATIONS

This task serves to identify PV system sizes appropriate for the former Holmes Road Landfill site, as well as provide conceptual design elements and PV system specifications and generation output.

5.1 PV System Size Options

Based on discussions with city staff, a 10 MW solar farm is the desired size for this project. A solar farm of this size utilizing amorphous silicon modules will require approximately 150 acres of land at the site. The city also stated that it may expand the project in future to encompass the entire 300-acre site, resulting in a 20 MW solar farm. For purposes of this analysis, the 10 MW system size was selected.

5.2 Conceptual Design Elements

The type of PV panels and mounting structures define the major conceptual design elements of the solar farm. The city has specified an AMAT or equivalent line of large amorphous silicon thin film panels measuring 2.2 x 2.6 meters with an estimated efficiency of 6-7.5 percent. These panels would be mounted on racks, facing due south, at an angle of 30 degrees above horizontal to maximize the system for annual energy production. The mounting racks would be aligned in rows along an east-west axis across the entire area defined for the project. Depending on the height of the panels off the ground, it is estimated that approximately nine to ten feet of spacing between rows would be required to prevent shading from one row of modules onto the other. This row distance is determined by the “design day,” or Winter Solstice, when the sun is at its lowest point above the horizon and casts the longest shadow. In addition, providing adequate distance between rows allows for access by maintenance vehicles or small cranes should system maintenance or module replacement be required.

In addition to the panels and racks, inverters will be required to convert the solar power generated from DC to AC power so it can be exported to the utility grid. The largest PV inverters available are 500 kVa (kW). These inverters are an ideal size, as each inverter would handle five percent of the power generated. In the event of an inverter failure, only five percent of the entire system would be unavailable for power generation. Many large PV systems also employ the use of a pre-wired spare inverter wherein if an existing inverter fails, the power is rerouted to the spare inverter. Use of a spare inverter eliminates any down time while the failed inverter is repaired or replaced. In addition, solar farms of this size would require a switchgear at the point of interconnection to the utility distribution system; however, the 500 kVa inverters have a built-in internal switchgear which negates the need for a single large switchgear. Inverters are placed on concrete pads, and should be placed strategically throughout the solar farm to minimize DC wiring line losses. Often, the inverters are placed in a row, in the center of the solar farm, perpendicular to the rows of solar panels.

In addition, the solar farm developer will need to work closely with CenterPoint Energy to meet all interconnection requirements for connecting with the power grid.

Figure 2 below provides a one-line diagram of the conceptual design elements of a 500 kW PV building block which would be replicated 20 times to achieve the desired 10 MW system size.

City of Houston Photovoltaic Project
Single Line Drawing for 500 kW Building Block Conceptual Design

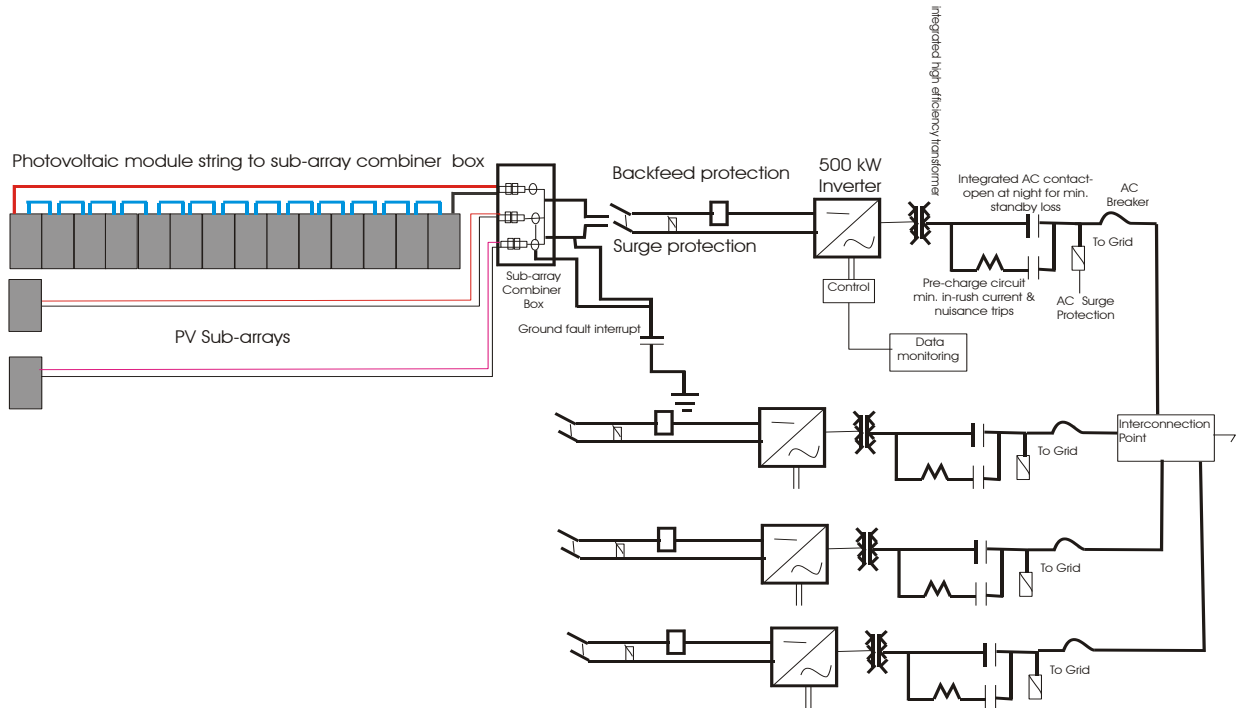


Figure 4. Single-Line Drawing for 500 kW Building Block Conceptual Design

5.3 PV Equipment Specifications

The final PV system equipment specifications will be determined by the project developer based on panel selection, design of wiring configurations, and the inverter voltage input window. The following is a list of equipment components and specifications based on current project information:

- 21,740 AMAT line (or equivalent) amorphous silicon PV modules (2.2 x 2.6 meters) in 20 x 500 kW sub-arrays
- 20 x 500 kVa (kW) line-tie power inverters
- Elevation angled (30 degree) fixed tilt mount structures (racks, piers, and footings)
- Balance of system components (hardware, wiring, connectors, combiner boxes, disconnects, metering and NEC required components)

5.4 PV Generation Output Analysis

SRA modeled the generation output of a 10 MW solar farm located at the former Holmes Road Landfill. SRA utilized the PVWATTS solar modeling program, an industry standard solar generation estimation tool.

PVWATTS utilizes Typical Meteorological Year (TMY) data, which is comprised of hourly historic meteorological data collected over a 30-year period (1961-1990), providing average hourly values that are used to predict the expected output of a PV system for any given day and hour of the year. The values for energy generation calculated with this model represent the expected output of the PV system in an average weather year.

For the former Holmes Road Landfill, SRA modeled a 10 MW fixed tilt (30 degrees) PV system with TMY data for Houston, Texas. SRA utilized a derating factor of 79 percent to account for the conversion of DC power to AC power, as well as to factor in system losses from module mismatch, inverter losses, DC line losses, and module soiling. Based on this analysis, SRA determined that a 10 MW DCp system (peak output of 10 MW DC) would generate approximately 12,526,260 kWh in an average weather year.

PV module output degrades over time, typically at the rate of about one percent per year. Based on this degradation rate, which corresponds to the warranty levels of most amorphous silicon thin film panels (20 years at 80 percent of rated output), SRA calculates that the 10 MW solar farm will generate approximately 326,000,000 kWh over its expected 30 year life.

SRA also analyzed the monthly energy generation profile of the proposed 10 MW solar farm. Figure 1 below provided a graphical representation of the number of kilowatt-hours that will be produced each month by the proposed system.

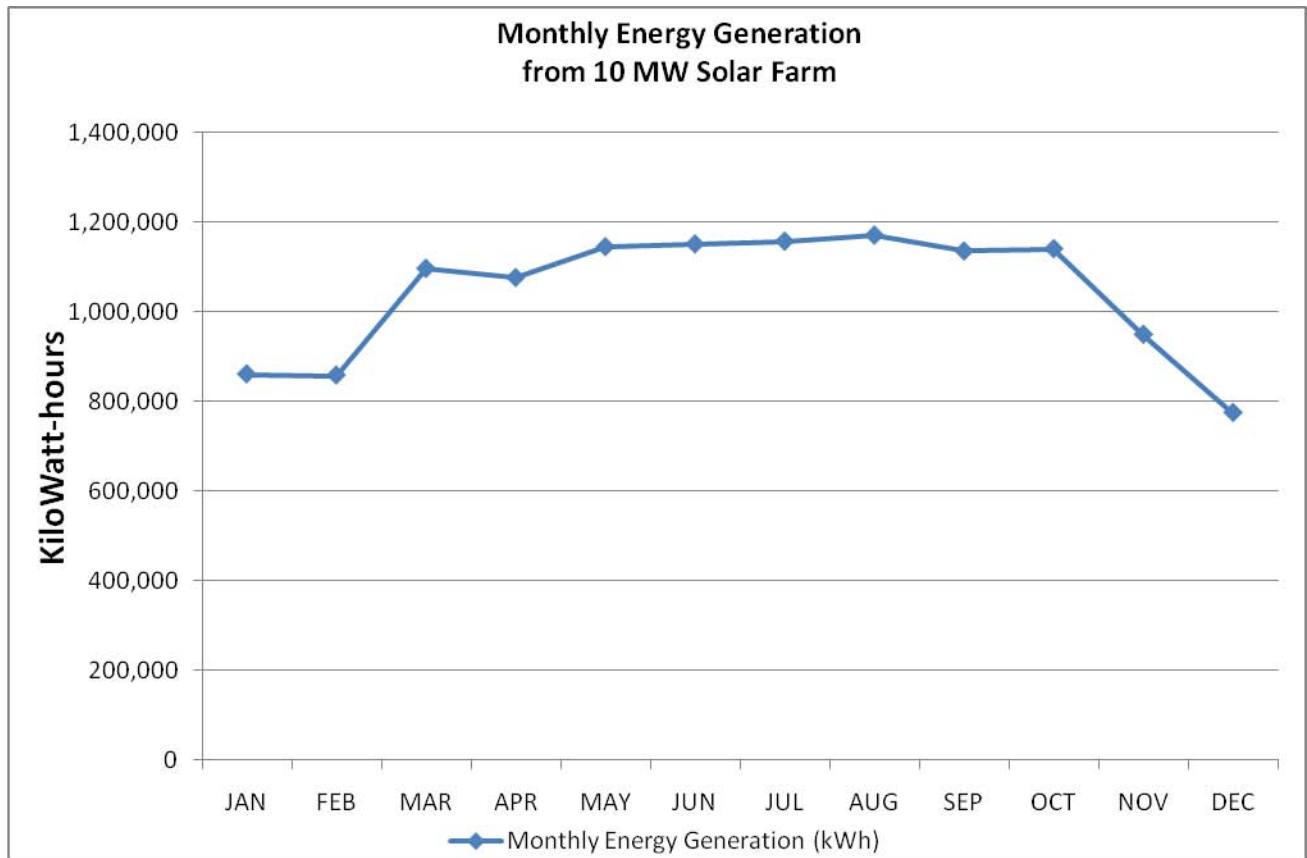


Figure 5. Monthly Energy Generation from 10 MW Solar Farm

6 TASK 5: DEVELOP INSTALLED COST ESTIMATES FOR THE SOLAR FARM

PV system prices have fluctuated in recent years due to supply constraints of silicon, advances in thin film technology, and increases in commodity costs (copper, steel, concrete, etc.) required for system construction. Currently, with recent advances in manufacturing technology, short-term declines in commodity costs, a predicted oversupply of silicon feedstock, as well as the recent eight year extension of the Federal solar credits which should bring stability to the U.S. market, industry analysts are forecasting a reduction in PV system costs going forward.

The city has indicated an interest in developing the 10 MW solar farm at the former Holmes Road Landfill with amorphous silicon thin film modules from an AMAT or equivalent production line. This is a relatively new production line process that manufactures large utility-scale panels approximately four times the size of conventional panels. This increased size provides an economy of scale over smaller panels on the market today.

All in costs for a turn-key installation utilizing utility-scale amorphous silicon panels from an AMAT or equivalent production line have been estimated to be as low as \$4.25/watt. For the purposes of this study, SRA determined that evaluating a range of costs would be the prudent course of action. Therefore, SRA developed “low,” “medium,” and “high” cost scenarios to arrive at a range of probable costs for the project, which will serve as an input variable in the economic analyses conducted under Task 6 of this project. The following values were selected for the three scenarios utilized in the economic analysis:

- Low cost scenario: \$4.25 per watt
- Medium cost scenario: \$5.00 per watt
- High cost scenario: \$5.75 per watt

These estimates are based upon costs for a typical project with minimal site preparation activities required. However, as documented in this study, additional site prep will be required at the former Holmes Road Landfill site. Additional costs will be incurred to the developer in the preparation of this site including clearing of trees and brush, grading, compacting, and possibly bringing in additional fill dirt. Based on a discussion with City of Houston staff, it was estimated that the additional site preparation costs would be approximately \$10,000 per acre (not including the cost of additional fill dirt, if required). Thus, this additional site preparation cost should be included in the turn-key cost of the solar farm. At an estimated 15 acres per MW of solar arrays, the additional cost of the project would be approximately \$150,000 per MW or \$0.15 per watt. Factoring in these additional site preparation costs, the turn-key cost estimates were adjusted to:

- Low cost scenario: \$4.40 per watt
- Medium cost scenario: \$5.15 per watt
- High cost scenario: \$5.90 per watt

Extrapolating these dollar per watt cost scenarios out to the proposed 10 MW scale results in total project costs of:

- Low cost scenario: \$44.0 million
- Medium cost scenario: \$51.5 million
- High cost scenario: \$59.0 million

7 TASK 6: CONDUCT ECONOMIC ANALYSIS OF THE PROPOSED SOLAR FARM'S CHARACTERISTICS

The final task of the feasibility assessment for a 10 MW solar farm at the former Holmes Road Landfill was to determine the economic value of purchasing solar power from the facility. Based on discussions with city management, it was determined that the city planned to purchase power generated at the plant from its electricity provider Reliant Energy. The plant would be designed, built, and financed by a third party vendor. The power would then be sold to the city via Reliant Energy through a power purchase agreement, and revenues from the power sales used to pay off the loan held by the developer.

The economic analysis conducted by SRA determined how much money the city could save on its electricity bills, over the life of the power purchase agreement, based on a standard set of assumptions. In FY 2008 the city purchased over 1,254,562,078 kWh of electricity for all city facilities, at a cost of more than \$141,000,000. Based on the modeled output of the 10 MW solar farm, the energy generated by the proposed solar farm would represent one percent of the city's annual energy purchases.

When purchasing power, the city pays both energy (kWh) and capacity (kW) charges. The first step in the economic analysis was to determine the base rate "blended energy" cost the city is charged for electricity based on energy and capacity charges. This was determined by taking the total costs of energy and capacity purchased in FY 2008 and then dividing by the number of kWh purchased. Based on data provided by the City of Houston General Services Department Energy Division, the blended cost of energy for city facilities was determined to be \$0.1128/kWh. This is the base rate that the proposed solar power purchases were compared against.

The next step in the economic analysis was to determine the estimated solar power purchase price based on a number of assumptions and cost scenarios. The assumptions utilized in this analysis were as follows:

- 10 MW PV System Annual Energy Generation: 12,526,260 kWh
- Life of PV System: 30 years
- Annual PV System Output Degradation: 1%
- Power Purchase Agreement Period: 20 years
- Federal Investment Tax Credit (ITC): 30% of system capital cost accruing in Year 1 of operation
- Depreciation Method: 5-year Modified Accelerated Cost Recovery System (MACRS)
- Finance Period for 3rd Party Developer: 10 years
- Finance Interest Rate: 6.5%
- Amount of Financing Required: 100% of capital cost
- Annual Energy Escalation Rate for Conventional Utility Electricity Purchases: 3.5%
- Annual Operations and Maintenance Cost of Solar Plant: \$0.005/kWh

Based on these assumptions, an annual cash flow analysis was conducted to determine the levelized cost of energy generated at the site. The levelized, or busbar, cost is the cost of energy generated by a power plant based on its lifecycle costs and estimated energy output over its expected life. The analysis was conducted in real 2008 constant dollars, and was performed by summing the annual plant costs over the 30 year PV system life. These costs included principle and interest payments on the developer loan and annual operations and maintenance (O&M) costs. Once the lifecycle cost was arrived at, the tax benefits of the ITC and MACRS were subtracted, and the resulting value was divided by the estimated plant output over 30 years. For the three

capital plant cost scenarios documented in the previous section of this report, the resulting levelized costs were determined to be:

- Low cost scenario (\$4.40 per watt): \$0.1137/kWh
- Medium cost scenario (\$5.15 per watt): \$0.1321/kWh
- High cost scenario (\$5.90 per watt): \$0.1506/kWh

The next step in the analysis was to estimate the power purchase costs via a power purchase agreement (PPA) with the city's power provider. This cost was estimated by adding a 10 percent profit margin to the levelized cost of energy, which is a standard rate of return for utility power projects. In addition, a \$0.005 adder was included to account for utility ancillary service costs (e.g., administration, billing, scheduling, distribution wheeling, and other associated utility costs of providing power). Based on the levelized costs determined above, the estimated power purchase costs under the three capital cost scenarios were determined to be:

- Low cost scenario (\$4.40 per watt): \$0.1300/kWh
- Medium cost scenario (\$5.15 per watt): \$0.1503/kWh
- High cost scenario (\$5.90 per watt): \$0.1706/kWh

The final step in the economic evaluation of the proposed 10 MW solar farm was to determine the cost savings to the city of purchasing solar power that displaces conventional energy purchases. One of the benefits of solar power is that its fuel from the sun is free, and is not subject to fluctuations in conventional fuel prices. Increasing prices of coal and natural gas are the major driver behind utility rate increases, and solar power provides a hedge against these rate hikes. For the purposes of this analysis, it was assumed that utility rates would increase, on average, by 3.5 percent per year to account for both fuel price increases and inflation. Solar power, alternatively, requires that more than 90 percent of its lifecycle costs be invested upfront as capital expenditures on the system. As a result, a solar farm's energy is generated at a fixed cost over its entire life. In analyzing the cost savings to the City of Houston of purchasing solar power, it was assumed that the city would enter into a 20 year PPA at fixed cost per kilowatt-hour over the contract life. Based on this assumption, the costs of purchasing the estimated output of the solar farm over a 20 year period was calculated, and then subcontracted by the estimated cost of purchasing utility power over the same period with a 3.5 percent price escalation factor. The resulting cost savings to the city were determined to be:

- Low cost scenario (\$0.1300/kWh): \$7,936,179
- Medium cost scenario (\$0.1503/kWh): \$3,561,526
- High cost scenario (\$0.1706/kWh): (\$813,126)

As seen from the above cost savings estimates, the negotiated purchase price of solar power is critical to the overall economics. Under the low cost scenario, the city would save nearly \$8 million over 20 years compared to conventional utility purchases, or nearly \$400,000 per year on average. It is important to note, however, that the cost of solar power will be higher than conventional utility power in the earlier years, until conventional costs of power increase to a higher rate than the fixed price of solar power. Based on the analysis completed for this study, it was determined that the crossover point, where solar will be less expensive than conventional power will occur around Year 6 of the PPA under the low cost scenario, Year 10 under the medium cost scenario, and Year 13 under the high cost scenario. Under the high cost scenario, it is estimated that the city may pay slightly more for solar power over the 20 year PPA period, approximately

\$40,000 per year on average, as the savings in the later years of the contract do not make up for the additional costs paid in earlier years.

Based on the economic evaluation results presented above, it is apparent that a PPA for the output of a 10 MW solar farm at the former Holmes Road Landfill can provide significant value to the city under the low and medium energy cost scenarios. The solar power purchase costs do not include values associated with renewable energy credits or carbon offsets, as it was assumed that these costs are passed through from the developer and utility to the city. Should these credits be included or otherwise monetized, they could significantly increase the value of the purchases. There are also other non-tangible benefits of purchasing solar power such as meeting local greenhouse gas emissions and sustainability goals. Factoring in these additional values would likely turn the high-cost scenario from a cost adder to a cost saving proposition.

8 CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

As can be seen from the analysis presented in this report, the development of a 10 MW solar farm at the former Holmes Road Landfill site is both environmentally and technically feasible, and the successful negotiation of a power purchase agreement for the solar electric plant's output can provide significant economic savings to the City of Houston over the term of the contract.

A number of conclusions were drawn from the report and are summarized as follows:

- The solar farm should be sited on the southern half of the site. Siting it on this portion of the land will place it adjacent to the point of grid interconnection, require less land to be cleared, provide increased visibility to the public, enhance site security, and not disturb the urban forest buffer zone adjacent to Sunnyside Park.
- Based on the type of solar module recommended for this project, and the type of mounting structure best suited for this site, it is estimated that approximately 15 acres per MW of solar capacity will be required. For the proposed 10 MW project, the total land requirement would be approximately 150 acres.
- The use of land over closed municipal solid waste landfills in Texas is regulated under the rules of 30 Texas Administrative Code (TAC) Chapter 330, Subchapter T. The majority of the rules covered under the TAC only apply to the development of "enclosed structures" on closed landfills, and solar power plants do not meet the definition of enclosed structures. However, several rules do apply to the development of non-enclosed structures, and would apply to the construction of a solar farm at the site (see section 3 for complete citations), namely:
 - Rule §330.953 requires soil testing prior to or during development and construction, and the September 2006 Terracon limited Environmental Site investigation likely meets this requirement. The City of Houston should ensure that all notifications required by §330.953(d) have been properly made.
 - Rule §330.954(e) requires an authorization request and approval prior to site preparation. Since the landfill cover will be disturbed, altered and partially penetrated the city and/or developer will need authorization to proceed with site preparation, and this request should be filed at least 45 days prior to commencement of site activities.
 - Rule §330.960 outlines the required contents of an authorization request for disturbing the final cover over a closed landfill for development of non-enclosed structures.

- Rule §330.957 requires a certification statement, and language for that statement, that is required as part of the authorization request.
- Rule §330.957(c) requires an existing conditions summary, and the required elements of the summary, that is also required as part of the authorization request.
- Rule §330.955 specifies miscellaneous requirements for developments over closed landfills which may or may not apply to the solar development depending on the final system design and construction requirements. These requirements include the placement of additional soil or building pads be placed on the final cover prior to construction to protect the integrity and function of the final cover; the allowance of small amounts of municipal solid waste removed from a landfill be redeposited in the landfill on a case-by-case basis; unauthorized pilings in or through the final cover of the landfill are prohibited; and unauthorized borings or other penetrations of the final cover are prohibited; any water coming into contact with waste becomes contaminated water and must be properly discharged; locations where waste is removed shall be backfilled and compacted with clay; and no waste shall be left exposed overnight.
- Rule §330.962 specifies the requirements for a written notice to be filed by the owner of property (i.e., solar farm) stating the former use of the land; the legal description of the tract of land; notice that restrictions on the development of land exist per Texas Health and Safety Code; and the name of the owner.
- Once the authorization for construction is approved, the site will require clearing of all trees, brush, and any other debris, and disposed of properly. Following clearing, the site will require grading, and possibly filling to achieve the minimum uniform soil cap depth of four feet minimum. After grading and filling, the site will also likely require compacting of the soil cap to protect the integrity of the final land fill cap and to minimize differential settlement at the site. During each stage of site preparation, it will be important to minimize disturbance of the soil cap and avoid the penetration of the cap into the waste material zone.
- Amorphous silicon thin film modules mounted on an elevated angle (30 degrees) rack structure is the preferred system configuration for this site due to its lightweight characteristics, which will be beneficial in minimizing pier depths, reducing impacts from possible differential settlement at the site, and lessening the amount of environmental mitigation of the site during project development.
- The amount of energy generated from a 10 MW solar farm at the site is estimated to be more than 12,500,000 kWh per year, equivalent to one percent of the city electrical needs.
- The cost of building a solar farm at the proposed landfill is estimated to cost between \$4.40 and \$5.90 per watt on a turn-key basis for the type of PV system specified in this report. The total cost of a 10 MW solar farm at the site is estimated to cost in the range of \$44 million and \$59 million.
- SRA estimates that based on the probable range of capital costs required for this project, as well as allowing for vendor profit and utility ancillary costs, the city's cost of purchased power from the solar farm would be in the range of \$00.13 and \$00.17 per kWh.
- Based on the range of prices estimated for the purchase of solar power, the city could potentially save nearly \$8 million in electricity costs over a 20 year contract life, or nearly \$400,000 per year under the lower price scenario. Under the high price scenario, the city would spend an additional approximately \$800,000 in electricity costs over the same period; however, if renewable energy credits, carbon offsets, and/or achievement towards city greenhouse or sustainability initiatives were valued as part of the purchases, then the resulting economics would likely be positive for the proposed purchases.

8.2 Recommendations

A number of recommendations are provided for the City of Houston's consideration in moving forward with the proposed 10 MW solar farm project:

- The city should immediately begin working with the local distribution utility, CenterPoint Energy, to determine the available line loading capacity of the distribution line paralleling Reed Road adjacent to the site. This information will determine whether the line can accept the capacity from a 10 MW solar farm at the site, or whether the line will need to be upgraded to accept the additional capacity. If a line upgrade is required, this could either delay the project, or require that the project be built in two phases.
- Once the project is approved and slated for development, the city should begin working with the developer to prepare an authorization request for construction of a non-enclosed structure on a closed landfill.
- The city should contact the Texas Council on Environmental Quality to determine if the 2006 Terracon Environmental Investigation meets the requirements for soil testing, or if additional investigation would be required prior to initiation of site preparation activities.
- In negotiating a power purchase agreement with its electricity supplier, the city should include the following factors in the negotiation process:
 - A firm, fixed price of electricity for kWh over the contract life;
 - A capacity credit value for peak kW generated by the plant;
 - A long (i.e., 20 year) contract period;
 - The value of the land where the solar farm is sited should be monetized, either in the form of a lower purchase, a capacity credit, or lease payment; and
 - Renewable energy credits accruing to the city should be included as part of the power purchase agreement.

Should the City of Houston decide to proceed with the proposed project, these recommendations will provide a jump start on the regulatory and PPA negotiation process, and move the project forward in an expedient manner to begin realizing the benefits of solar power as part of its electricity resource purchase mix.